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Abstract: The Earth stratosphere contains aerosols of various origins. An experiment is proposed to fly a filter on a stratospheric balloon, catch stratospheric dust (aerosols) on this filter and perform an analysis of this dust on-ground.

Keywords: *Stratospheric dust, aerosols, BEXUS*-7; *stratospheric balloon; aerosols;*

Abstract

The Earth's stratosphere contains aerosols of various origins, including aerosols of volcanic and cosmic origin. An experiment is designed to collect aerosols in the stratosphere and do a post-recovery analysis. The experiment consists of a pump sucking air through a filter that is able to catch particles down to $0.3\mu m$. It will fly on a stratospheric balloon, launched from Esrange by Eurolaunch in October 2008 as part of the BEXUS 7 campaign. A system of tubes and valves will ensure that no air flows through the filter before or after the balloon reaches floating altitude. Upon recovery, the filters will be collected and analysed using electron microscopy and neutron activation analysis.

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1 Introduction

Balloon flight campaigns, especially BEXUS, do not only bring us a little closer to space, they also provide unique insight into the environmental conditions in the Earth's stratosphere. The stratosphere is an atmospheric layer, just above the troposphere, in a height of approximately $10\,km$ to $50\,km$.

One of the most interesting stratospheric environmental conditions is the prevalence and nature of stratospheric dust: Stratospheric dust is dust from volcanic eruptions, dust stemming from outer space or dust of human origin and it has an influence on the world climate. Our project therefore aims at performing a "census" of stratospheric dust. A concept for a light and cheap filter probe has been developed, this probe shall be flown to this atmospheric region of interest and be recovered for laboratory analysis.

1.1 Overview

The document structure is based on supervisor guidelines. Here follows a brief overview of some of the elements of the document. This overview is far from complete; please refer to the table of contents for a complete reference of the document contents.

After the introduction, the core experiment is described in section (2). The scientific goals are outlined in section (2.1) and the experiment is summarised in section (2.2). Then follows a description of all hardware (electronics, pump, filter, structure) in section (2.3) and software in section (2.4).

Section (3) contains all interfaces and design requirements. Of particular importance here is section (3.1.1) on fault tolerance design and section (3.1.2) on safety.

In section (4), verification (4.1) and testing (4.2) are discussed.

The ground station in discussed in section (5).

The rest of the document is concerned with information related to management (section (6)).

The first appendix, appendix (A), contains various diagrams relevant to the electronics. Secondly, appendix (B), contains information about major document versions. Appendix (C) consider the outreach programme. Appendix (D) contains scientific background information on the mission. A full component is shown in appendix (E). This includes budgets for mass, volume and cost. A Gantt chart is shown in appendix (F). Finally, a list of abbreviations is shown in appendix (G).

The document concludes with a full bibliography.

1.2 Acknowledgements and sponsors

We would like to thank the following people, organisations and companies for their support:

- IRV for providing financial and other resources
- IRV staff for their time and effort
- IRF for the opportunity to use resources available there
- Esrange, for giving us the opportunity to fly on a balloon
- The personnel at Esrange for their time and effort
- All members of the review panels for their valuable advice
- Eurolaunch
- Swedish National Space Board
- European Space Agency
- Progressum, for financial support
- Elmarco, for providing the filter
- Chip45, for providing the microcontroller
- Tommi Juopperi, for his significant help in designing the electronic circuit

2 Experiment description

2.1 Scientific Objectives

The key mission objectives of Stratospheric Census are:

- To design and develop a simple yet powerful concept of collecting dust in the stratosphere.
- To collect stratospheric dust during a BEXUS campaign using a filter and to recover the filter sample.
- To use different techniques of analysis (in particular neutron activation analysis and electron microscopy) for assessing the relative frequency of elements in stratospheric dust in the northern hemisphere subpolar region.
- To measure, during the campaign, pressure and temperature of the ambient air.

In addition to the scientific objectives, Stratospheric Census has the educational objective to gain, as students, knowledge and experience.

2.2 Experiment summary

The main idea is to measure the stratospheric dust profiles by collecting air and pumping it through a filter during a balloon flight. The pump that will be used is discussed in section (2.3.4), the filter choice discussed in section (2.3.5). To ensure that only stratospheric dust is collected, the filter has to be sealed off by valves during the launch and ascent of the balloon. Those valves are treated in section (2.3.3.1). Once the balloon reaches floating altitude, they are opened and they are closed again before the balloon descends. This process is controlled from the ground via a radio link ("E-link"). Commands are sent by a ground station computer (section (5)) and received and executed by a microcontroller on the balloon (section (2.4)). In case of a radio link failure, the microcontroller can work autonomously. Various sensor data is downloaded from the balloon, indicating the status of the experiment.

After the mission, the received filter is extracted and given to post-flight analysis (section (2.5.4)). The results will be published in a final report.

Parts of the experiment are Commercial Off The Shelf (COTS) components (pump, valves, filters, etc.) while the PCB board and the mechanical structure (2.3.3) are produced by the team itself.

2.3 Hardware

2.3.1 Components

A complete list of components with references to the relevant data sheets can be found the table in appendix (E).

2.3.2 Electronics

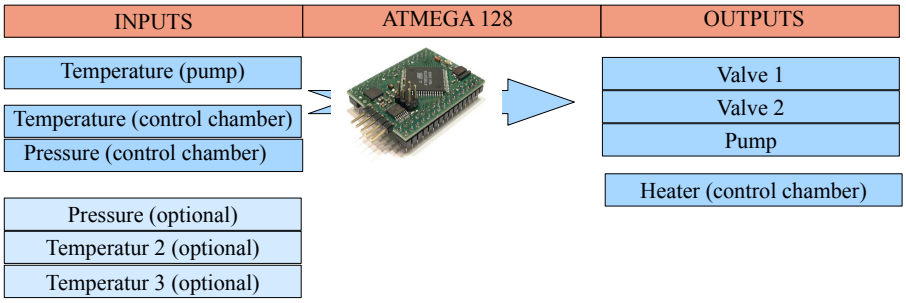


Figure 1: Schema for the information flow

The heart of the electronics control system forms an ATMEGA128 microcontroller on a Crumb128 board. It senses pressure and temperature from various points and makes decisions when to switch on the filtering unit. A logical schema can be seen in figure (1), a circuit diagram is in figure (17) on page (64) in appendix (A.1).

2.3.2.1 Temperature The temperature is measured inside the control system, at one point on the surface of the pump and optional two additional points. This is done by means of a voltage divider formed by a thermistor and a 30k resistor. The resistance of the thermistor is calculated by the B-parameter equation.

$$R = R_0 e^{B(\frac{1}{T} - \frac{1}{T_0})}$$

For the Epcos thermistor [8] $B = 3970$ at $T_0 = 300K$. In combination with the resistance it yields the following voltage vs. temperature curve. The voltage is fed into an analog input of the microcontroller.

The microcontroller is connected to the heating panel of the control unit and the heating clamp of the filtering unit via relays. These are switched on

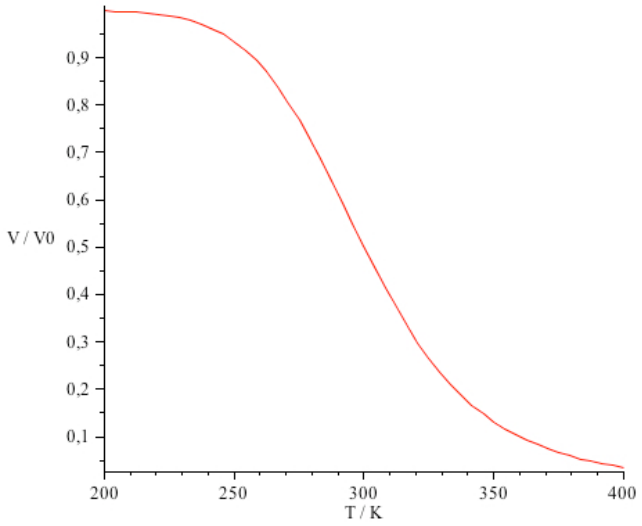


Figure 2: Voltage as a function of temperature for an Epcos thermistor.

when the temperature drops below a certain temperature. The sensor on the surface of the pump is for safety reasons. It assures that the temperature of the pump is known at every time and can be switched of in case of exceeding a temperature threshold.

2.3.2.2 Pressure The pressure sensor is a critical part of the electronic subsystem. It determines the altitude and launches the filtering process. Decision was made for the ASDXDO series by Honeywell which provides an absolute pressure range from 0 to 103 kPa. This sensor is placed inside the control unit. For correct operation an outgassing hole is provided.

2.3.2.3 Filtering Unit The components of the filtering unit, i.e. the valves and the pump, are connected with power mosfets which can be turned on with the corresponding bits.

2.3.2.4 Downlink The TTC system of the balloon is accessed via the RS232 connection of the microcontroller. The crumb128 supplies a driver for that. The system will be attached to a MIL-C-26482 plug as stated in the BEXUS user manual [22].

2.3.2.5 Heating To prevent freezing of the components through the outgassing hole heating resistors are soldered onto the PC board. If the temper-

ature inside the control chamber drops below a certain threshold the resistor network is switched on by the corresponding MOSFET. Six resistors are put in parallel, each of them providing $(24\text{V})^2/680\Omega = 0.85\text{W}$ of heat.

2.3.2.6 Risk analysis Please refer to section (3.1.1.1) for a safety analysis of the electronics subsystem.

2.3.3 Structure

The structure that will support all the experiments components will be constructed from aluminium. This material was chosen because it is light, stiff and easy to work with. This choice was also supported by IRV as they have considerable stocks of aluminium plate and rod. The design of the structure will be developed now that all other components have been selected.

2.3.3.1 Pipe substructure The pipe substructure of Stratospheric Census comprises of three line connected to the pump.

The pump that we have chosen (the process of which is described in section (2.3.4)) has two BSPP 1/8" ports. Although this diameter is suitable for the system, finding suitable components that would connect directly proved difficult and for costs sake it was decided to use simple adaptors to switch to 1/8" NPT connections. By using this small diameter, there is greater risk of the filter being plugged by particles however, due to the low concentrations, this should not be a problem. By staying with this line diameter, there is also the added benefit of weight reduction compared to earlier design iterations.

For all fittings, stainless steel was chosen.

As per the requirements of the pump [16], all loads are on the suction line. In order to run the pump at a low speed to avoid seizing, two inlets are available to the suction port of the pump that can be switched using a 3-way switching valve couple to an electric actuator.

The primary initial line begins with a simple valve as shown below in figure (3). This valve's function is to stop contamination of the filter during the ascent and descent of the balloon to ensure that the dust collected is all stratospheric. The filter assembly is connected between this valve and Valve B so that both valves and the filter can be removed to avoid contamination when removing the filter for analysis. This is connected by a short length of pipe that will be used for any sensors necessary to monitor the flow to the pump (via an adaptor).

The collection intake line is a straight pipe from the exterior of the gondola so that the pump can draw a small quantity of air through the system. This is to allow the pump to operate at low speeds during the ascension of the

balloon avoiding the possibility of seizure. The inclusion of a valve at this point was necessary in any case as it must be possible to isolate the filter for removal at the end of flight. The exhaust is simply released into the gondola's interior as it will not disturb Stratospheric Census' or other experimenters' apparatus.

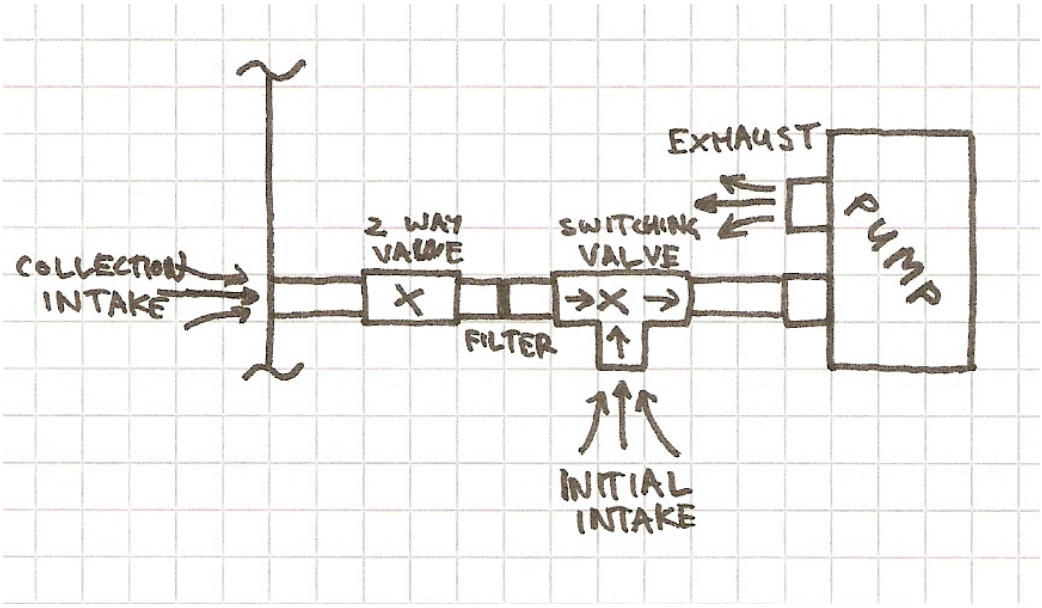


Figure 3: Sketch of the pipe.

Figure (4) shows the CAD design from various angles.

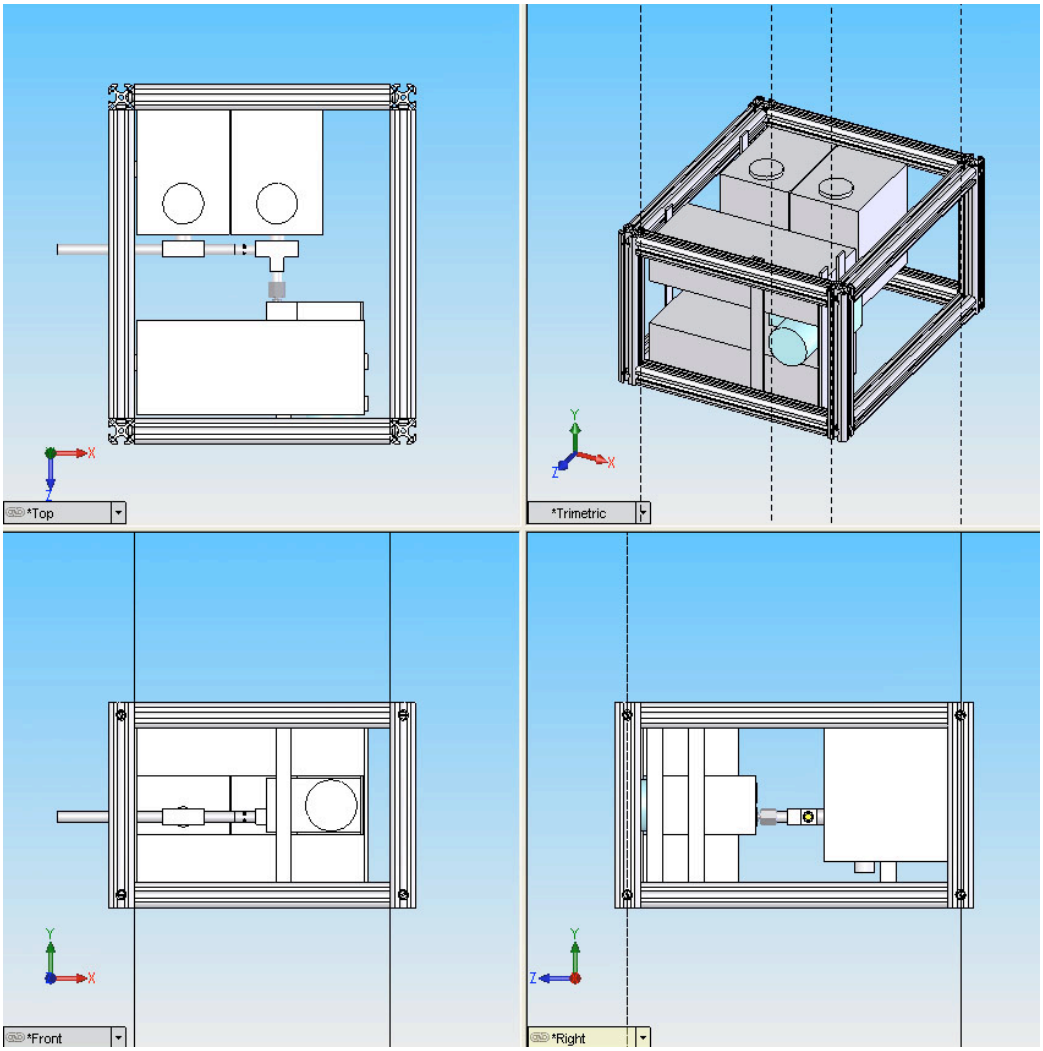


Figure 4: Structural design of the experiment.

2.3.3.2 Manufacturing techniques Mark Fittock has been directly involved in the construction of numerous engineering projects in the past. However, this has not included prior experience with construction of pipe and pump systems. The other students involved in the project have more limited experience.

2.3.3.3 Volume budget Originally Stratospheric Census requested a volume of 200*200*300mm. However, this was a very rough estimate and now that the problem has been extensively explored, a volume of 300*350*200mm will be required.

The length of 350mm has been estimated using the total length (for correct orientation and taking into account the threads) of the components required for the primary intake line.

The height requirement of 300mm is dictated by the actuators, Valve B and the elbow used. It would be possible to reorient this system and this may result in a smaller height.

The 200mm width is to allow space not only for the pipe and pump subsystem which requires approximately 100mm but also the control and battery array. This has been given considerable space so that the batteries can be securely attached and to minimise risk of damage to the PCB.

2.3.3.4 Frame Stress Analysis For the frame, some stress analysis was conducted. Firstly, the failure mode needed to be ascertained. Using worst case assumptions, the longest length of the frame was used for buckling calculations (300 mm). The max force that could be withstood before buckling occurs was calculated using:

$$F_{buckle} = \frac{\pi^2 EI}{\nu^2} \qquad [N]$$

Where E is the Young's Modulus of the material, I is the second moment of inertia and l is the length. This gave a value of 110 kN for the max load before buckling. Due to the reasonably short length compared to profile ($I = .0143\, m^4$).

In order to find a critical loading limit, the plastic limit of the aluminium was found so that it could be compared with the buckling limit:

$$F_{plastic} = \sigma_{plastic} A_{cs} \qquad [N]$$

Where the cross sectional area was approximated from the density of aluminium and the weight of 1 metre of the bar. Using a plastic limit of 270 MPa for this bar as was selected by [12, page 17] the maximum load was found to be 69 kN.

Comparing this to a rough force estimate of 8 kN by using 10 kg at 10 g as defined by with a shock factor of 2 [15, page 280] and a safety factor of 4 [15, page 263] shows that the structure will be able to withstand particularly brutal shocks caused by malfunctions of the balloon system. This is important where the sample collected during flight is particularly vital to the success of the flight.

2.3.3.5 Flow Analysis In order to verify that a pump selected would be sufficient to overcome the pressure losses caused by the pipe system, simple

fluid flow calculations were conducted. The head losses of the two inlet lines were compared and it was clear from inspection that the line with the valves and the filter would cause a larger pressure drop.

From limited information supplied by Elmarco it was found the loss coefficient for a one layer filter (albeit thicker than the one we selected) was equal to 1.64. Through concern for the possible blocking of the filter from ice particles (despite a low probability), a value of 10 was used instead for the filter. The loss coefficients of the entrance, valves and connector were calculated using the approximations from [20, table 8.2 page 289, figure 8.22 page 482] Using the Properties of the U.S. Standard Atmosphere [20, page 834] and the filter approximation, the pressure loss was calculated to be 0.17 Pa using [20, equation 8.36]. This is well below the pump performance in atmosphere, a pressure difference of 9 mbar from [16]. However, the pump will not operate to these standards at the low temperatures and pressure that it will be subjected to, rigorous testing will be required to ensure that the design is sufficient (as detailed in it's testing section (4.2.5)).

2.3.3.6 Vibration Analysis Vibration analysis will be conducted by testing after the experiment has been assembled. This information will be shared with other experimenters using the same platform and if the amplitude or frequency are likely to cause problems, vibration mitigation methods can be investigated.

2.3.4 Air Pump

The pump is one of the most crucial components of Stratospheric Census. It is required to operate under the conditions prevalent in the stratosphere, that is temperatures down to $-90°$and pressures of $10-20\,mbar$. Under these low pressure conditions - a medium vacuum - the lack of convective cooling also poses the risk of overheating. At the same time, power consumption should not exceed what can easily be provided with batteries and the pump should be light and small while still providing the necessary throughput of air.

Typical candidates are therefore vacuum pumps designed for the medium vacuum range (defined from $\approx 3\,kPa = 30\,mbar$ downwards). Usually, these pumps are designed to produce a vacuum against atmospheric pressure. For Stratospheric Census, the pump will work against the "ambient" medium vacuum which should have a positive effect on the possible throughput. On the other hand, the low temperature has a negative effect on the throughput as the molecules will stick to surfaces much longer at low temperatures.

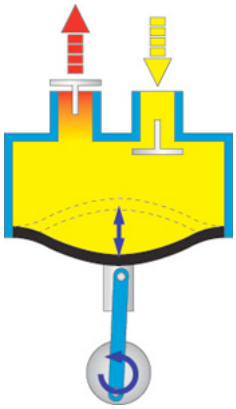


Figure 5: Diaphragm Pump

2.3.4.1 Pump types For a medium vacuum, the most used and reliable type of pumps are rotary-vane and diaphragm pumps.

The team of Stratospheric Census decided to use a diaphragm pump (figure 5) , for the following reasons:

- Diaphragm pumps are dry pumps, they do not outgas oil.
- The diaphragm itself insulates the air stream against contamination from the rest of the pump.
- Diaphragm pumps are reliable, readily available and economic.
- There is less friction than in rotary-vane pumps.
- A diaphragm pump has already been used successfully on a BEXUS balloon in the very similar SADFACE experiment [7].

Possible disadvantages of diaphragm pumps:

- Depending on the material of the diaphragm, it might become brittle in the cold and could therefore break.

Decision has been made to use the N 89 KNDC from KNF [16].

2.3.5 Filter and Sensor Subsystem (Payload)

2.3.5.1 Filter requirements To get a meaningful detection, the mass of the caught particles needs to make up at least 1 ppb (parts per billion) of the mass of the filter.

An estimate of the relative mass of the particles:

$$C = \alpha \frac{M_p}{M_f} = \alpha \frac{N m_p}{M_f} = \alpha \frac{n V m_p}{M_f} = \alpha \frac{n \phi t m_p}{m_f} \tag{1}$$

In equation (1), C is the relative mass of the caught particles, α is the sticking ratio, considering the amount of particles that are attached to the surface of the hose or that fly through, M_p is the total mass of the caught particles (kg), M_f is the mass of the filter (kg), N is the total number of particles, m_p is the average mass of the particles (kg), n is the particle density (m^{-3}), V is the total volume of air sucked in (m^3), ϕ is the air flux ($\frac{m^3}{s}$), and t is the total time (s) in which air is sucked in.

If one estimates values for the different quantities in equation (1) one can estimate the relative mass.

If we take $\alpha = 0.5$, $n = 10^5 m^{-3}$, $\phi = 2\frac{m^3}{\text{hour}}$, $t = 5$hours, $m_p = 1\mu g$ and $m_f = 100g$, one gets a relative concentration of:

$$C = 0.5 \cdot 10^5 m^{-3} \cdot 2\frac{m^3}{\text{hour}} \cdot 5\text{hour} \cdot \frac{1\mu g}{100g} = 0.005$$

Of course, all of the values are very rough estimates. However, the estimated value is more than six orders of magnitude above the necessary value of $C = 1 \cdot 10^{-9}$, so even if all of the values are much worse than estimated here, it is still likely that we can detect particles.

The filter property that is relevant is really the flux divided by the mass. If the filter is twice as heavy, and the flux is twice as high, the detection is, in the end, the same.

This does not take into consideration the contamination.

2.3.5.2 Choice of filter High requirements must be served by the filter in order to catch dust particles down to a size small as 0.3 μm. Also the filter must not be affected by the low temperature, neither should it allow water vapour to freeze on it and, in that way, degrade the filter. The decision was made for the Nanospider ^{TM} Technology which was developed by Liberec Technical University (Czech Republic) and is now manufactured by Elmarco. This type of filter consists of cellulose filtration material treated with PA6 polymer nanofibers 100 to 500 nm in diameter. During a test it was able to catch NaCl particles of 0.2 μm with an efficiency of almost 80 % where particles of 1 μm were captured fully. [21] Chosen filter with mass density of the nanolayer material of $0.19g/m^2$ causes a pressure drop of $178Pa$ which requires the pump to build up a pressure which is more than two times larger than ambient pressure.

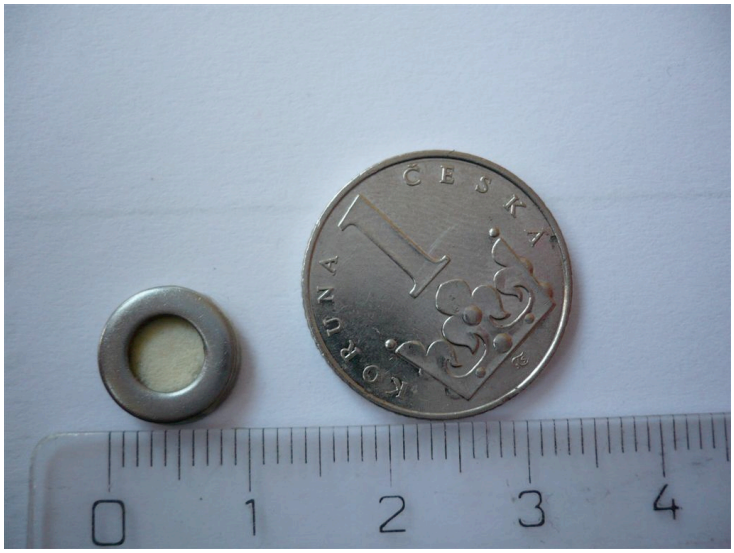


Figure 6: A preliminary design of the filter

The team will acquire two identical filters, and compare a filter which has flown with a filter which has not flown when doing the analysis.

2.4 Software Overview

2.4.1 Computer Systems & Data Storage

Stratospheric Census will be equipped with a microcontroller ATMEGA128-CAN, sponsored by chip45. It provides $4\,kB$ of non-volatile EEPROM and $4\,kB$ of volatile SRAM memory. Within the control box where electronics and microcontroller are housed, a temperature sensor will monitor the thermal conditions. A heating element is provided to assure that the temperature stays within the operating range of the ATMEGA128, from $-55\,°C$ to $125\,°C$. It can be switched on as needed.

2.4.2 Qualitative Software Requirements

The experiment is launched with the filter valves closed and the pump operating at a low speed. During the ascent of the balloon, temperature and pressure are recorded and transmitted to the ground. Once the balloon reaches its floating altitude, the filter valves will be opened and the pump cycled up with a command from the ground. However, if the uplink is not operational, this should happen automatically if pressure drops below a certain level or if a certain amount of time has passed since launch. Once the balloon leaves the floating altitude, this process has to happen in reverse order. (Close the filter valve, switch off the pump.)

The pump is controlled by the means of PWM (Pulse Width Modulation) to allow the setting of a specific voltage. At the beginning of operation, it can therefore be run at a lower speed. During the campaign, the number of cycles is then be increased step-wise if pump temperature (risk of overheating!) permits.

The heating elements are controlled automatically by the microcontroller with reference to a threshold temperature. However, they can also be controlled manually from the ground if need arises. Data will be stored in two different packet configurations, “data packet” (containing dynamic data, i.e. temperature, pressure and time) and “status packet” (containing data about pump, valve, heater status and operating mode). “Data packets” will be sent every $10\,s$, “status packets” upon ground station request or when a status variable changes.

Based on these qualitative requirements, the operation of Stratospheric Census is structured into three different modes, defined in the following sections.

2.4.3 Normal Mode

Ideally, the experiment will be in "Normal Mode" for the whole mission duration. Prerequisite for this is a working up- and downlink. The microcontroller will then:

- monitor constantly pressure and temperature
- generate data packets from the current pressure and temperature at a standard interval of 10 s and transmit them to the ground
- expect an "OK" from the ground after every packet to assure that up- and downlink are working
- listen to commands from the ground station
- acknowledge commands from the ground station by sending an ``OK''-packet / status packet
- control the heating elements automatically

2.4.4 Autonomous Mode

"Autonomous Mode" is entered from "Normal Mode" if more than 4 minutes have passed since the processing of the last command from the ground. (After 2 minutes without command, a warning is issued.) "Autonomous Mode" is left if any command is received.

The microcontroller will:

- monitor constantly pressure and temperature
- control the pump and valves automatically
- listen for commands from the ground
- record data packets from the pressure and temperature sensors at a standard interval of 10 s and transmit them to the ground
- store part of these packets in EEPROM memory
- determine whether the floating altitude has been reached by monitoring time and pressure
- control the heating elements automatically
- control pump cycles automatically to prevent pump overheating

- store a status packet together with a data packet in EEPROM memory if a status change occurs

Whether the floating altitude has been reached will be determined by comparing the current pressure and time with predefined values. If the time threshold has been passed or if the pressure has been below its threshold value for at least $2\,min$, another warning message will be transmitted. After additional $2\,min$, the valves will be opened and the pump started unless some ground station interaction occurs before. The same procedure applies for the descent. As it is difficult to judge when descent will happen, pressure will be the only indicator for the stop of the experiment.

2.4.5 Further Details

Technical details on packet structure, a complete flow diagram, etc. are given in section "Experiment Software and Autonomous Functions", section (3.7).

2.5 Operation

2.5.1 Measured and calculated flight information

The following is measured directly using sensors (apart from the actual collection of particles using the filter):

- Two temperature sensors, one to measure the pump temperature, one to measure the control box temperature. This information is needed for heater and pump control.
- One optional temperature sensor.
- One pressure sensor to measure the ambient pressure. This is used to assess whether the experiment should be started.

2.5.2 Location in the gondola

Because of the nature of the experiment, it is highly essential that the experiment is closed to one of the sides of the gondola. That leaves the choice of the viewing direction: up, down or to the side. It is expected that contamination would be lowest if the viewing direction for our experiment is straight down (see the section on contamination (3.9) below). For that reason, the preferred viewing direction is straight down.

2.5.3 Pre-flight procedures

In the last days and moments before launch, the following tasks need to be carried out by various team members:

- Oct 2nd, the final functional test is carried out, by the whole team
- Oct 2nd, the filters are placed in the experiment using a clean bench, by Mark Fittock
- Oct 3rd, the ground station will be setup, by Martin Siegl
- Oct 3rd, a hole will be drilled through the gondola floor, by Mark Fittock
- Oct 3rd, the military standard connector will be soldered, by Martin Rudolph
- Oct 3rd, fix outside temperature sensor with thermal paste
- Oct 3rd, fix battery temperature sensor with thermal paste
- -120 min, the experiment will be mounted to the gondola, the electronic connections will be fixed, and the experiment will be connected to the Elink by Mark Fittock and Martin Rudolph
- -30 min, the electronic connectors are checked, by Martin Rudolph
- -30 min, the tube is opened, by Mark Fittock
- -30 min, the experiment is plugged in, the microcontroller is started, by Martin Rudolph
- -30 min, the link and the temperatures are checked, by Martin Siegl
- 0 LAUNCH

2.5.4 Post-flight Analysis

After the retrieval of the payload, the filters will be dismounted in a clean-room at either Esrange or IRF and shipped to the Institute of Experimental and Applied Physics, Czech Technical University, Prague, Czech Republic. Subsequently, two techniques will be used for analysis.

Electron microscopy will be used for evaluation of the main structure of the aerosols. The size gives useful information about the origin of a particle

(volcanic, cosmic or contaminate). The spatial distribution of specific elements can be studied. An image of a filter similar to the one that will be flow can be seen in figure (6).

The core analysis technique is Coincidence Instrumental Neutron Activation Analysis (CINAA) [13], a technique able to detect the composition of multiple isotopes. This will be carried out by the Czech Nuclear Institute, using a neutron specific dose at Research Reactor LVR-15 for activating sample for about 100ppm strong analysis by gamma spectroscophy on site focusing on heavy metals. We are expecting to find transitions between specific types of isotopes of Fe, In and Co mainly. These isotopes were not there previosuly as the previous calibration analysis confirmed (personal corespondence, results come-up soon) The method is very precise and can be used to detect a sub-ppm fraction of elementary abundance for up to 74 elements [17] [5]. This technique will be used both on the filter that has been flown, and on the filter that has not been flown, so that the structure of the filter itself can be removed by digital post-processing (simple subtraction).

Heavier elements have larger nuclei, therefore they have a larger neutron capture cross-section and are more likely to be activated by fast neutrons. That is of great benefit, because we are mostly interested in those heavy elements, although only present in stratosphere in trace amounts. The method is nearly free of any interference effects as the samples are transparent to both the probe (n) and analytical signal (gamma ray). CINAA is applied instrumentally (no need for sample digestion or dissolution), so there is little if any opportunity for reagent or laboratory contamination. The team will focus on iron, nickel and cobalt isotopes, and will try to find out very spare ones of iridium and similar as well. The team expects isotopes of those elements (Fe, Co, Ni) originating from volcanic eruptions in slightly altered than naturally occurring well-measured ratios. Heavier nuclides are present as well [19]. A main advantage of the CINAA is the possibility to distinguish terrestrially uncommon isotopes, thus recognising them as of cosmic origin. Among others, Fe(60) or Ni(60) can be some of the clearest indication of an extraterrestrial source. Also the Fe(57)/Fe(54) relative composition differs strongly for terrestrial and cosmic sources.

3 Experiment Interfaces and Design Requirements

3.1 General Design Requirements

3.1.1 Fault Tolerance Design

3.1.1.1 Electronics A risk of failure of the electronics subsystem must be kept as low as possible since a complete failure of the electronics would result in a failure of the experiment. However a complete failure is unlikely due to excessive testing. In the worst case the microcontroller fails. This will be discussed in the risk analysis in the microcontroller chapter.

In addition single components of the electronics might fail.

1. The power supply connection might fail. This risk is kept low by having redundancy strings of batteries connected via a diode to the other battery packs.

2. If the pressure sensor fails the system can still be controlled by the ground station. A double failure of the sensor and a connection loss might result in a complete failure of the experiment when it happens during critical phases, i.e. opening and closing the valves.

3. Failures in valves or pump might result in false conclusions drawn from the neutron activation analysis.

3.1.1.2 Microcontroller Safety & Risk of Failure No immediate safety risk stems from the microcontroller itself.

As the hear of the experiment in terms of controlling pump, heaters and valves, a microcontroller malfunction poses a high risk for total failure of Stratospheric Census.

- Loss of microcontroller power: Problems with the microcontroller power supply can occur. Temporary power loss leaves the chance of recovery (microcontroller reset), total power loss is fatal.

- Microcontroller in infinite program loop: This is prevented by using the watchdog functionality, very low risk.

- Wrong command interpretation: Commands are secured with a checksum, very low risk.

- Temperature outside microcontroller operating range: If temporary, very low risk for the experiment. If permanent, possible loss of the experiment.

- Loss of a sensor or communication with a sensor: Loss of the temperature sensor in the control box can be fatal for the microcontroller. Loss of the temperature sensor on the pump can be fatal for the pump. Loss of pressure sensor in conjunction with loss of ground communication (Autonomous mode) can lead to a delayed experiment start.

3.1.1.3 Structure In order to avoid failure propagation for the structural components, most components are bracketed to a frame structure that connects to the strong and rigid exterior frame. In the case that a component does manage to break away from another, they should remain fixed to the other components. Of concern are the large mass components such as the pump and actuators. Particular care has been taken to ensure that they are secured and redundant beams have been used.

Although the pump used is small and not running at a high frequency, failure propagation is still a concern. Although the experiment should withstand catastrophic failure of the pump, if it is of concern for other experiments further measures can be taken to protect from projectiles that may occur during malfunction.

3.1.1.3.1 Single point failures Due to the limited scope of this project, multiple redundancies were not possible for many of the components. The high cost of the pump and actuators means that only one pipe system could be used. Unfortunately, this results in multiple single point failure possibilities.

In order to lower the possibilities of pump failure during flight, the pump that was chosen has been previously tested in the stratosphere and seen to start and run in temperatures much below the specifications. However, if the bearings seize or another malfunction occurs, flow will be limited or cease entirely.

The valve and actuator assemblies are both single points of failure but design decisions have been made to reduce this impact. Critical failure will occur if the valves fail to open at the beginning of sampling. However, if failure occurs during sampling, the valves should automatically switch back and protect the material collected from contamination. If the valves freeze shut or open, as the temperature rises again, control will either be regained or they will automatically close. In this way, although critical failure can

occur if the valves can not be opened, failure during sampling should not be fatal to the results of the experiment.

3.1.2 Safety Concept

The experiment does not contain any electro-explosive devices, pressurised containers or radioactive sources. It contains batteries. Batteries can be chemically hazardous when leaking, but this should not happen.

The experiment contains a pump that causes vibrations and can thus cause problems for other experiments on or near the gondola. A vibration test will be carried out to determine the frequencies as described in section (2.3.3.6).

All mechanical parts comply with Swedish industry safety standards. All moving parts are either completely or practically sealed off, no specific instructions regarding safety are needed for this.

3.1.3 Materials

Because of the nature of this experiment, a number of different metals were selected depending upon the applications. Although aluminium is preferred for many uses, it is not suitable for others.

3.1.3.1 Aluminium The frame and structure of the experiment are constructed from prefabricated beam materials. Although aluminium is both light and easily worked, there are difficulties with such a balloon flight and the temperatures that will be experienced. Due to the high coefficient of thermal expansion, aluminium was deemed inappropriate for the piping due to leakage concern.

3.1.3.2 Brass Brass fittings were selected over the more standard steel fittings due to the reduction in cost. Brass retains the low friction and low coefficient of using steel whilst being cheaper. The reduced durability of the fittings is not a concern because of the low operating period of the equipment.

3.1.3.3 Steel It was decided that for the piping, steel would be used. The low coefficient of expansion was the deciding factor for using the steel and since the amount of piping required is not large and the diameter small, the mass payoff was deemed acceptable.

3.1.4 Declared Components List

A full components list can be found in appendix (E).

3.2 Mechanical interfaces

Figure (7) shows the simple bracket that will be used to attach the frame to the base. Four of these will be used to connect the frame to the structure. These can either be connected to the inside or outside rails of the frame at any point along their length.

3.2.1 Accommodation Requirements

This total frame requires 350*300*200 mm before including the brackets for attaching this to the gondola floor. These brackets can either be attached on the inside face of the frame or outside depending on convenience and volume restrictions.

The 300*200 mm face must face downwards and have access to the atmosphere in order to take samples whilst minimising contamination. Apart from this, the design has been made to be highly flexible as is desired for a case where arrangement changes may need to be made close to the launch.

3.2.2 Attachment Concept and Foot Pattern

In the name of flexibility, the attachment concept has been kept as simple as possible. The advantage of using a frame with rails allows the use of brackets that can be attached anywhere along the length of the frame. Both balloon gondola possibilities use M10 bolt connectors but it is unknown yet how far apart the bolt rails are inside the gondola. The bracket and bolt arrangement can be seen earlier in figure (7).

A sketch of the connection to the gondola can be seen in figure (8).

3.3 Thermal interfaces

3.3.1 Thermal Design

3.3.1.1 Thermal Design Requirements For different subsystems different thermal requirements apply. Critical part of the control box is the pressure sensor, which provides compensated data from $0°C$ to $85°C$. The battery box should be kept on a level as high as possible to $70°C$ (Figure (9)) to get maximum performance. The pump specifications state that it will operate between $5°C$ and $40°C$. However, it has flown previously and operated

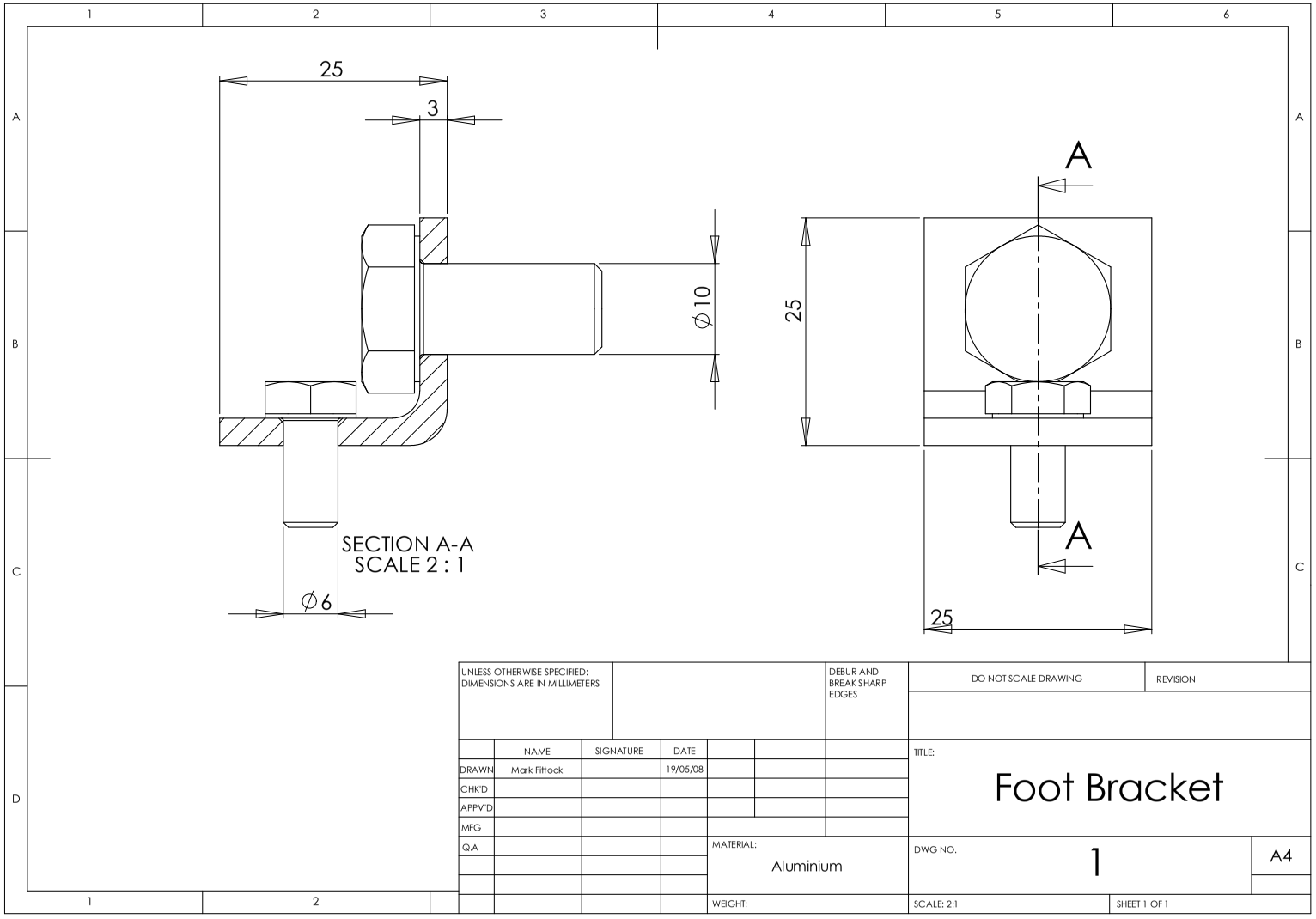


Figure 7: MICD drawing

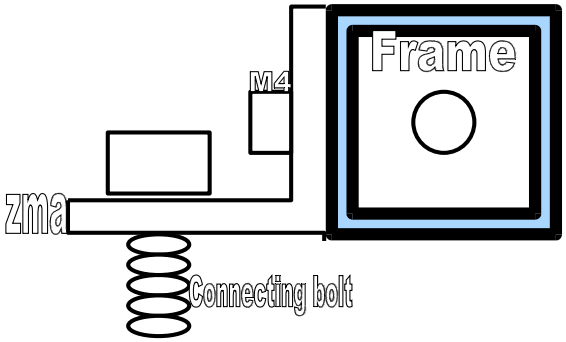


Figure 8: Drawing of the connection to the gondola

without any active thermal control. Due to the temperature fluctuations, critical elements of the structure must take into account the changes in size.

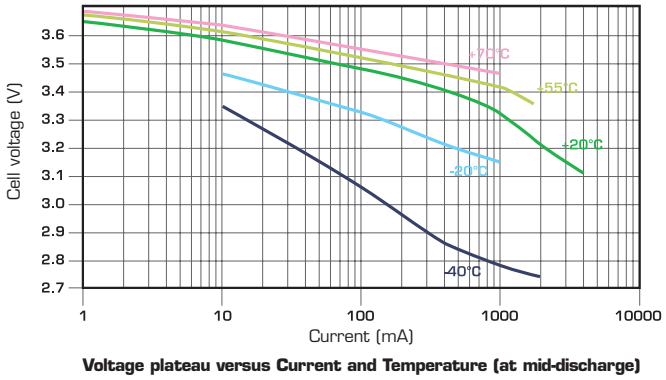


Figure 9: LSH 20 performance

3.3.1.2 Thermal Design Description The temperature of the control box can be actively controlled by a 5 W heater. Verification is done by testing. Optional thermal blankets or the use of thermal paste is possible to finetune the design.

The temperature of the battery box will be controlled passively by thermal insulation. In addition to that self-heating of batteries will be used to keep the desired temperature.

In order to reduce the chances of the heater getting too cold or seizing when operation begins, it will be started before launch. This will be thor-

oughly tested beforehand and if it is found that this method will not operate successfully, then insulation will be added as is required.

In order to avoid loss of seal due to changes in pipe diameters as the temperature varies, steel was selected for their low coefficients of thermal expansion. Flexible sealant will also be used to ensure the air-tightness.

3.3.2 Thermal Interfaces

The experiment has conducting interfaces through the structure to the gondola. This will be the main part of power dissipation since convection is negligible in high altitudes.

3.3.3 Temperatures and Thermal Control Budget

3.3.3.1 Temperature Ranges See Appendix, TBD.

3.3.3.2 Temperature Monitoring Temperature of the control box and at three further critical points outside the control box is continuously measured. Critical points have to be determined by experiment.

3.4 Power interface requirements

3.4.1 General Interface Description

For the electronic components two potentials are needed, namely 12 V (pump, actuators, heaters) and 5 V (control system). The 12 V potential is achieved by placing three batteries (3.6 V, 13Ah, SAFT LSH20) in series forming a potential of about 10.8 V. This simplifies the design because a regulator for these components can be omitted. However, verification of full functionality has to be done. For simplicity this potential is denoted by 12 V in the following. The 5 V potential is regulated down from the 12 V potential.

3.4.2 Power Distribution Block Diagram and Redundancy

Two battery packs are connected via diodes to have double redundancy. A block diagram can be seen in figure (10).

3.4.3 Experiment Power Requirements

An overview of the power requirements can be seen in table (1). This table yields a total charge consumption of 15.45 Ah. For total redundancy two

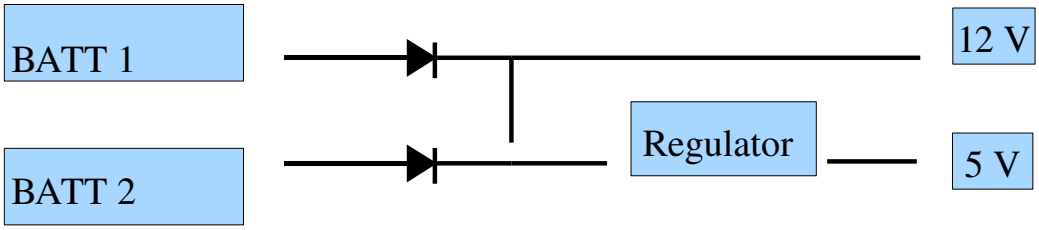


Figure 10: Power distribution block diagram

strings for each battery pack are needed. Each of them has 3 batteries. Thus a total of 12 batteries is needed.

Component	**Power [W]**	**Potential [V]**	**Current [mA]**	**Duration [h]**	**Charge req [Ah]**
Control System	2*	5	0.4	10	4
Regulator	3*	10	0.4	10	3
Heater	5	10	0.5	5	2.5*
Actuator	18	10	1.8	0.25	0.45
Pump	11	10	1.1	5	5.5

Table 1: Experiment power requirements. The figures marked with an asterisk (*) are based on estimation. Verification for those is required.

3.4.4 Interface Circuits

The main PCB will be connected to the E-link provided by Esrange via a shielded twisted three wired cable. On the E-link site it will be connected via a MIL-C-26482 series I connector. The control box provides a circular socket for this interface (see section (3.5).

The MIL-STD connector will be borrowed from Esrange for the time of flight.

3.5 Connector and Harness Requirements

3.5.1 Interconnection Harness Block diagram

Figure (11) shows the external interfaces provided by the control box. The circles indicate the individual sockets and are denoted with acronyms having

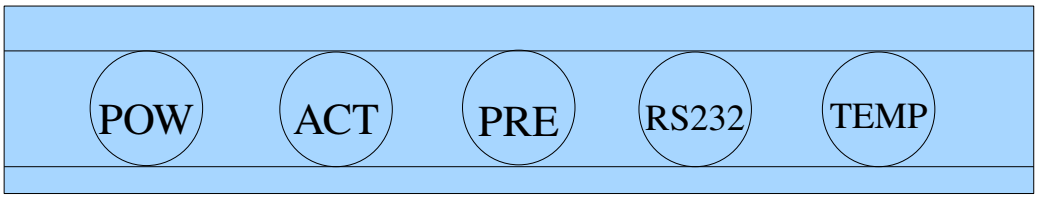


Figure 11: Connector diagram. See text for an explanation.

the following meaning:

POW Power line in

ACT Actuator and pump interface

RS232 Serial connection

TEMP TEMP: Interface to three external temperature sensors (two optional)

3.5.2 Interconnection Harness Characteristics

All interconnections are foil shielded with the shield grounded to the control box.

3.5.3 Connector Types

For all connectors the 680 series manufactures by Binder is used [2]. All sockets are female to protect the circuit from accidental outside shortening. Thus all connectors, including the power connector are male. Later does not cause any danger due to voltages of maximum 12V.

As mentioned before, the MIL-STD connector will be borrowed from Esrange for the time of ight.

3.5.4 Connector Pin Allocation

See appendix (A.3) for a full table with pin allocations and configurations.

3.6 OBDH Interface Requirements

3.6.1 E-Link connection

An RS-232 connection to the E-Link unit is required. It will be used at 9600 *bps*, with one packet comprising 1 start, 8 data, 1 stop bit. No flow

control.

3.6.2 Channel Allocation

Interface	Main
Telemetry & Monitor Downlink	1
Telecommand Uplink	1

Table 2: Experiment OBDH Interface Channels

In the E-Link connection, these channels are shared with other experimenters.

3.6.3 Bit Rate Requirements

Stratospheric Census does not continuously transmit data. Data packets are sent every $10\,s$, status packets upon request and/or status change. The operational scenarios, as outlined in the software descriptions are "Normal Mode" and "Autonomous Mode". For these, the bit rate requirements are:

- Worst-case Minimum ("Autonomous Mode"): $0\,bit/s$
- Normal ("Normal Mode"): In a $10\,s$ interval, it has to be possible to transfer one data packet and, if need arises, one status packet (downlink). A safe lower limit therefore are $50\,bit/s$.

If, in "Normal Mode", this bit rate cannot be sustained, the buffer of the E-Link unit would slowly be filled up by the Stratospheric Census microcontroller.

3.6.4 Timing

No requirement on timing information for the experiment on the balloon. A real time counter, counting the seconds since power-on, will provide a timestamp for the packets. On the ground, this can be matched to real clock time.

3.6.5 Monitoring

Stratospheric Census monitors the temperature on the pump and in the control box housing the electronics. For experimental purposes, the pressure is measured as well. Based on the temperature values, either the microcontroller (in "Autonomous Mode") or the ground station (in "Normal Mode")

takes the necessary actions. Commands are verified by the microcontroller based on a CRC-checksum, their execution acknowledged either by an OK-packet and/or a status packet.

3.6.6 Electrical Interface Circuits

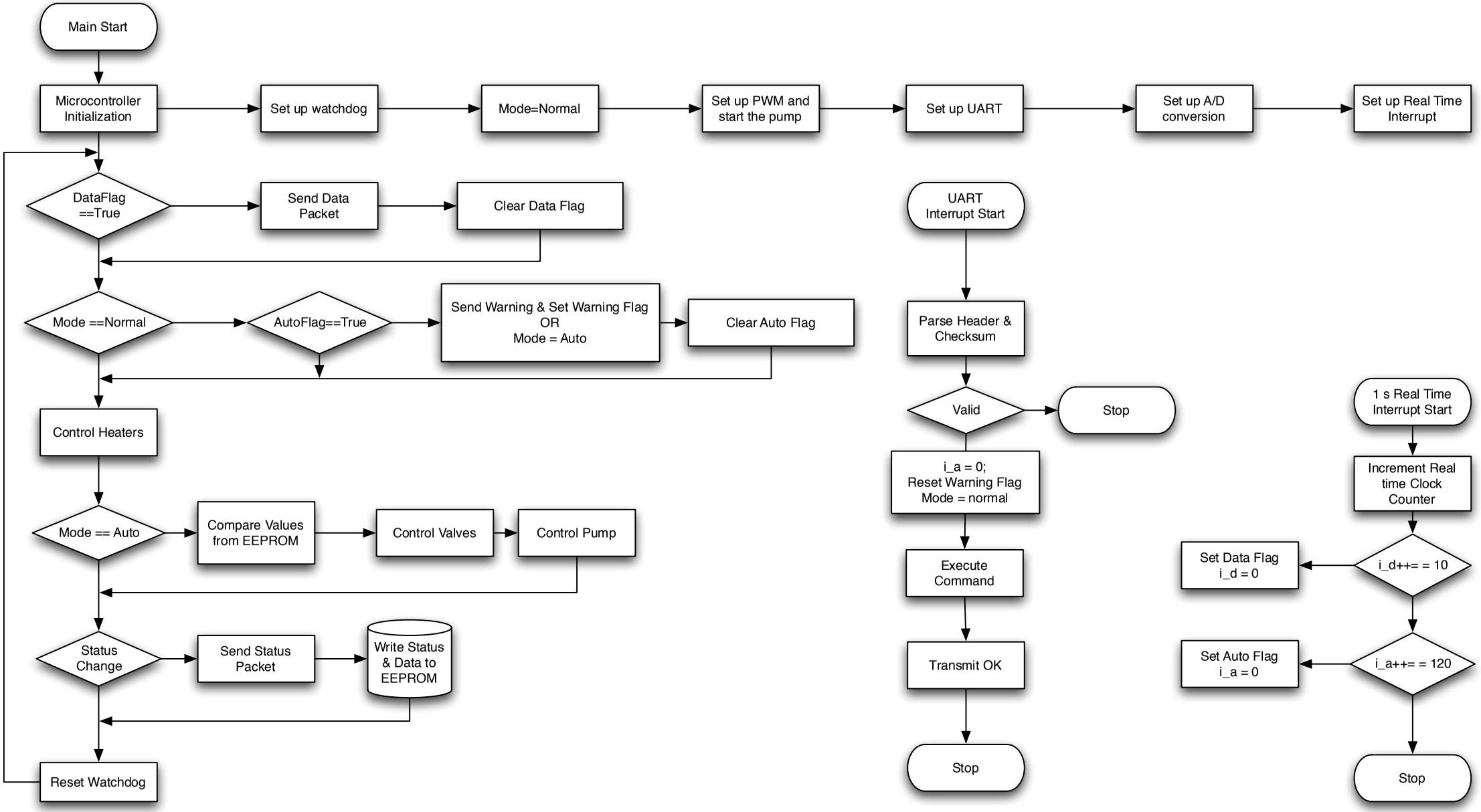
Except for the RS-232 connection, there are no electrical interfaces outside the experiment. Since RS-232 uses a GND-line, the whole experiment has to be grounded to the E-Gon gondola to share a common ground with the E-Link unit.

3.7 Experiment Software and Autonomous Functions

3.7.1 Software Flow Diagram and Functional Requirements

The software flow diagram for the microcontroller (next page) shows the complete code structure, including the switching of modes and the interrupt handling. Transmission to the ground and data saving to the EEPROM is indicated as well.

Stratospheric Census: Microcontroller Flow Diagram



3.7.2 Design for Redundancy & Shutdown

The "Autonomous Mode" was designed to provide absolute independence from the ground station in terms of controlling the experiment. Together with the fact that all data taken during "Autonomous Mode" is stored in memory, this should make the mission immune to temporary up- and downlink failures. After the connection is reestablished, all data recorded in the meantime can be sent to the ground. For longer ($\gg 30\,min$) up- and downlink failures, not all data can be stored due to finite memory capacity.

In the case of a temporary power shutdown, the microcontroller will recover on its own, albeit the data stored in SRAM will be lost. The microcontroller watchdog will guarantee a reset in case of an accidental infinite loop in the code.

3.7.3 Pump (Instrument) Operating Modes

The pump can be operated at different speeds, depending on the supply voltage. This supply voltage is controlled by the means of PWM and a MOSFET. In order to avoid a pump start in the stratosphere, the pump will be in a low-cycle operating mode during ascent and - upon reaching the desired altitude - will be cycled up to full speed as temperature permits. Once the experiment is started (valves open) the pump voltage is slowly increased to $12\,V$ ($\approx 1\,V$ per minute) , monitoring the temperature. Should the maximum temperature be reached, the voltage is lowered again until a stable and thermally acceptable working point has been found. The details of the control loop have to be determined in a thermal test. For "Autonomous Mode" it will be based on safe and conservative assumptions.

3.7.4 Packet Definitions

"Data packets" and "status packets" have a length of $15\,bytes$, including a CRC checksum byte to assure data integrity and a timestamp (from the real time counter). A data packet and a status packet are saved in the EEPROM after a status change. (A status change can be switching the heater on/off, changing the pump cycle, etc.) In "Autonomous Mode", data packets are also saved periodically, the interval dependent on memory consumption. Assuming a data taking rate of once every $10\,s$, the $4\,kB$ EEPROM on the ATMEGA128 could save data for $\approx 30\,min$. The data packet looks as follows:

Byte	1	2	3	4-5	6-7	8	9-10	11-12	...
Content	$	P	D	ID	time	,	temp 1	temp 2	...

...	12-13	14	15
...	pressure	CRC checksum	\r

The first byte ($) indicates the start of the packet, the second byte identifies the sender ("P" = probe), the third byte describes the content ("D" = data). A two type ID assures the correct identification of every packet.

The status packet is similar ("S" = status):

Byte	1	2	3	4-5	6-7	8	9	10	...
Content	$	P	S	ID	time	,	pump	heater	...

...	11-12	13	14	15
...	valves	mode	CRC checksum	\r

"Command packets" are kept shorter to reduce the risk of corruption during transmission.

Byte	1	2	3-8	9	10
Content	$	G	command	CRC checksum	\r

The first byte ($) indicates the start of the packet, the second byte identifies the sender ("G" = ground), bytes 3-9 are for the command itself and the checksum.

3.7.5 Telecommand Definitions

The possible commands are:

- ‘‘OK’’ , to signal a working connection every 10 s
- ‘‘HELO’’ , to check the uplink (handshake)
- ‘‘OV’’ + ID, to open the valve with ID
- ‘‘CV’’ + ID, to close the valve with ID
- ‘‘HEON’’ + ID, to switch on the heater with ID
- ‘‘HEOF’’ + ID, to switch off the heater with ID
- ‘‘PUMP’’ + 1 byte,
  to switch the pump to a certain operating voltage (0=off, 256=full speed)
- ‘‘STAT’’ , to get the current status packet

- ‘‘STPR’’ + 2 bytes,
  to set the threshold pressure for start and stop of the census phase (for automatic mode), is written to EEPROM, preset to a value TBD before launch
- ‘‘STTI’’ + 2 bytes,
  to set the number of seconds from launch onwards until the start of the census phase (for automatic mode), is written to EEPROM, preset to a value TBD before launch
- ‘‘AUTO’’ to switch the microcontroller manually to “Autonomous Mode”
- ‘‘GETP’’ + 2 bytes ID, to get the packet (data or status) with ID that was previously saved in memory
- ‘‘DATP’’ to get a current data packet

The possible responses from the balloon are:

- a “data packet”, responding to the command ‘‘GETP’’ ‘‘DATP’’
- a “status packet”, responding to the command ‘‘STAT’’
- command + “OK”, responding in all other cases

3.7.6 Handshaking

Data packets serve as a heart beat signal from the experiment as they are transmitted every $10\,s$ and signal a healthy downlink. The ground station responds with ‘‘OK’’. Since it is not possible to determine from the whether the uplink is working, the ground station will, once every minute, send a ‘‘HELO’’ - command, waiting for a ‘‘HELOOK’’ .

3.7.7 EEPROM

The EEPROM can accommodate $4\,kbyte$ of data. $1\,kbyte$ is reserved for status change packets and their corresponding data packets, the remaining $3\,kbyte$ are for the saving of data packets during autonomous mode (can be sustained for $30\,min$ until old data has to be deleted).

3.8 Electromagnetic Compatibility Requirements

3.8.1 General EMC Requirements

Radiated emission will be kept as low as possible using filters for outgoing connections and shielded wires for pump and external sensors. The main part of the electronics is placed in a metal control box. The design is sufficient also to reject interference from outside the experiment.

3.8.2 Specific EMC Requirements

The external temperature sensors form a high impedance line, susceptible to picking up noise. Apart from the above stated electronical action taken, the software will compare several measurements to filter out incorrect measurements.

3.8.3 Grounding

In addition to grounding the experiment in itself it is grounded to the gondola. This is inevitable, since a connection between the control box and the E-link has to be established. A grounding diagram can be found in figure (18) in appendix (A.2).

3.9 Cleanliness Design and Contamination Control Requirements

Particles in the stratosphere can be of volcanic, extraterrestrial or anthropogenic origin. A particular case of particles from anthropogenic origin are particles that originate from the balloon, the gondola, or its payload (including the own experiment) and caught by the filter immediately. Those are particles that we are not interested in and are outside the scope of our experiment; they are thus considered to be contamination. There may also be ice particles that are neither anthropogenic, nor aerosols, though those are rare in the very dry stratosphere.

Since the team will fly a man-made experiment, contamination is an issue as well. Apart from the common composition of materials from which the experiment structure is built, there exists a local deviation from the standard Earth isotope ratio conditions. The balloon launch platform contains material from the regional iron-ore mining, thus introducing a magnetite contamination. Fine grains may stick to the aluminium gondola and detach later during the flight, possibly entering the experiment. The iron ore from Kiruna has slightly specific ratio's of nuclide compositions.

It is safe to assume that all surfaces and materials in the balloon-gondola-system will outgas. Outgassing can result from desorption, diffusion and decomposition. [25] The amount of mass loss due to diffusion is given by:

$$\frac{dm}{dt} = q_0 \frac{e^{-\frac{E_a}{RT}}}{\sqrt{t}} \tag{2}$$

In equation (2), q_0 is a reaction constant to be determined experimentally, E_a is the activation energy, typically between 5 and 15 $\frac{\text{kcal}}{\text{mole}}$, R is the universal gas constant, T is the temperature and t is the time. This equation was derived for a vacuum. The stratosphere is no vacuum, but the atmospheric density is considerably lower than in the lower troposphere, so this may be a reasonable approximation.

If one assumes that particles travel straight paths relative to the balloon after outgassing, one can estimate the amount of impacted particles using view factors. Unfortunately, this assumption cannot be made, because the pump is actively sucking air from the environment. The situation will thus be considerably worse.

It is difficult to estimate theoretically not only how many particles will diffuse from the surfaces, but also how many of those will be caught in the air flow through the filter. It depends on many variables, many of them poorly known: the viewing direction for the hose, the distance to surfaces outgassing particles, the path that those particles travel (whether they fall down or float), the sucking power of the pump (from what distance such particles will be caught), the presence of other experiments outgassing particles, and probably a number of other factors. The "worst case scenario" approach does not work either; the worst case would be catching an outgassed particle big enough to block the valve completely; this is probably a highly unlikely scenario.

A good knowledge of the profiles of stratospheric dust is required to be able to tell apart contamination from actual measurements in the neutron activation analysis.

Despite all this, a very rough estimate is made.

The following sources of contamination are identified:

- The balloon (B)
- The gondola (G)
- Other experiments (O)
- The own experiment (E)

For each of those, the amount of contamination for the experiment can be approximated as the product of the outgassed mass times the fraction of outgassed mass that impacts the surface.

Source	amount (g/hour)	fraction	impact (g/hour)
Balloon	10^2	10^{-5}	10^{-3}
Gondola	10^{-1}	10^{-4}	10^{-5}
Others	10^{-2}	10^{-5}	10^{-7}
Us	10^{-3}	1	10^{-3}
Total	10^2	$2 \cdot 10^{-5}$	$2 \cdot 10^{-3}$

Table 3: Estimates for outgassing amounts. Note that those are extremely rough estimates and that the estimated values can be off by three orders of magnitude or even more.

In table (3) are estimates for the outgassed mass. The figures in this table are highly unreliable, and need to be updated as more information becomes available. We estimate to receive around 0.1 gram of stratospheric dust and 2 milligramme contamination per hour. This would be an acceptable contamination level, as it would in total be around 1% of the mass of the captured aerosols, which would in turn be around 0.1% of the mass of the filter (all very rough estimates).

3.9.1 Mitigation

Even without knowing how much contamination we can expect, we can list a number of techniques to use to prevent contamination as much as possible.

Contamination from the balloon is expected to be worst during launch and during descent. Our experiment has a front valve preventing any particles from entering the hose during launch and ascent up to stratospheric altitude. This valve is as close to the front as possible, so that as few particles as possible can stick to a surface between the valve and the ambient atmosphere. This valve will close again before descent, so that contamination during descent and impact is as low as possible.

The distance between the pump (with the filter in front) and the ambient air is as small as possible, so that the surface area of the hose, which will outgas particles, is minimised.

The preferred viewing direction for the experiment is straight down. It is expected that this will be the optimal direction to prevent contamination, particularly from the balloon.

3.9.1.1 Recovery The experiment needs to be treated with care upon recovery, in order to minimise the chance that the filter gets polluted.

4 Verification and testing

4.1 Experiment verification plan

Verification of the experiment is an important part of the project. All designs are made such that verification and testing is possible, and a significant amount of time is reserved for this in the time plan.

4.1.1 Objectives

The objective of the verification is to make sure that all subsystems, as well as the whole system, comply with the specifications, requirements as well as the boundary conditions as defined by Eurolaunch.

4.1.2 Responsibilities

Each person is responsible for the verification of the part that he has designed, and the whole group carries collective responsibility for the verification of the whole system.

4.1.3 Verification by Analysis

All subsystems are checked and double-checked before the final building, so that errors in the design can be identified as early as possible.

4.1.4 Verification by Test

Testing is a very important part of the design of any experiment, particularly if this experiment is outside reach after launch, such as is the case on a satellite, rocket or a stratospheric balloon. Thorough testing is thus necessary.

4.1.5 Verification Control System

4.2 Experiment test matrix

Tests can be divided into tests that verify that the own experiment is working, and tests that verify that the experiment is meeting the requirements for flight (e.g., not harming others and not harming the flight train). After all the parts have been tested individually (see the following sections), the parts will be put together and the whole system will be run to check that the pump and the valves are working correctly. The vibration test is of particular

Experiment unit	Mechanical Interface Inspection	Mass properties	Electrical Performance Test	Functional Test	Strength Test	Sine Vibration	Random Vibration	Shock Test	Low Pressure	EMC	Calibration	Thermal Properties
Control box	M	M	M	F								
Battery box	M	M	M									
Pump	M			F					M			M
Filter	M											
Sensors	M			F							C	
Total	M	M		F		A		A	A	A		

Table 4: Experiment test matrix. M stands for Measurement, A is Acceptance, C is Calibration, and F is a Functional Test. Details on all tests can be found in the text.

importance for not harming the surroundings, see section (2.3.3.6) for details on that.

4.2.1 Microcontroller Testing

Microcontroller qualification testing can be structured into the following parts:

1. Test of operating modes and operating mode switching
2. Test of sensors
3. Test of memory management
4. Test of heater control
5. Test of pump temperature control
6. Test of valve control
7. Test of "Autonomous mode" experiment control
8. Test of commands and communication link
9. Test of command parsing, command rejection and CRC checksum processing

Most of these are simple works / does not work tests. However, for heater control, pump control and the "Autonomous mode" experiment control in general, the test of the microcontroller code has to happen in conjunction with temperature and pressure simulations. This way, the reaction of the control loops can be checked.

4.2.2 Microcontroller Qualification Requirements

The microcontroller is qualified for flight if it:

1. has full functionality.
2. successfully passes a long-term running test (at least $5\,h$) in "Normal Mode".
3. successfully passes a long-term running test (at least $2\,h$) in "Autonomous Mode".

4. successfully controls the experiment while it is in the space simulator.

5. successfully controls the heater under varying (fluctuating) temperature conditions.

The test of "Autonomous Mode" (3.) should be part of a full worst-case test including

- simulated loss of communication, several times during ascent and during floating
- fast temperature fluctuations (simulated by stimuli or real) in the $-50\,^{\circ}$ to $50\,^{\circ}$ range
- loss of power during ascent, floating and in "Autonomous Mode"

A report shall be given for each of the prescribed tests. It shall contain the final test parameters and the test result. In case of non-compliance.

4.2.3 Electronics Testing

4.2.3.1 Control Box All electronic components are commercial with different industrial standards. Temperature ranges are stated in appendix (E). However, all critical components are inside the heated control chamber, which should always be kept between 0C and 85C to make use of the internal calibration of the pressure sensor in this range.

4.2.3.1.1 Results of control box thermal test The electronic box has been tested thermally using a thermal chamber. The temperature was raised from room temperature up to $50\,^{\circ}$C. The temperature sensors were calibrated using this thermal chamber. No flaws were detected during this.

4.2.3.1.2 Results of control box vacuum test The electronic box was placed in the vacuum chamber, without any connection to outside. The pressure in the vacuum chamber was rapidly reduced to 40 kPa.

No bursts of components were detected and all soldering spots remained faultless.

4.2.3.2 Batteries The batteries will according to their manufacturer lose or gain performance depending on there temperature (see figure (9)) The passive thermal control system must be tested with batteries working at full load. Preferably the temperature should be kept as close to $70°C$ as possible. Means of finetuning the design are thermal wrapping or thermal paste.

4.2.3.2.1 Results of battery thermal test The thermal battery test was performed by placing one battery in the thermal box. This battery was fixed with insulation foam. A current of 1 A was drawn out of the battery. During this, no extraordinary increase in temperature was measured.

From this, it can be concluded that no thermal paste between the batteries and the box will be necessary. However, the system will behave differently in vacuum, and for that reason, a temperature sensor is placed on the batteries.

4.2.4 Pump Testing

The pump (KNF Neuberger N89 KNDC-12V) has to undergo the following test procedures:

1. Basic functional tests (immediately after delivery)
2. Air flow measurements under ground pressure conditions: The curve of airflow vs. vacuum pressure (see datasheet [16]) should be reproduced if possible.
3. Air flow measurements under stratospheric pressure conditions: The same test as in 2.) performed in a vacuum chamber (space simulator) at $10\,mbar$. The obtained curve (airflow vs. pressure) can be used to for flow predictions.
4. Monitoring the pump temperature during operation under stratospheric pressure conditions (space simulator).
5. If possible: Monitoring the pump temperature during operation under stratospheric pressure conditions and cold temperatures.
6. Test of the vibrational spectrum of the pump. This is to assure that no other experiments can be affected by these vibrations.
7. Test of electromagnetic interference of the pump with other electronic components.
8. Final operation test (with all tubing attached) in the space simulator.

The pump is ready for flight if it is in working condition and can be kept from overheating under stratospheric pressure and temperature conditions.

4.2.4.1 Vacuum Test

A vacuum test for the pump will be performed in a small chamber at IRF in Kiruna. The small chamber was chosen due to its permanent availability. The goal of the test is to assess if and how fast the pump might overheat under stratospheric conditions.

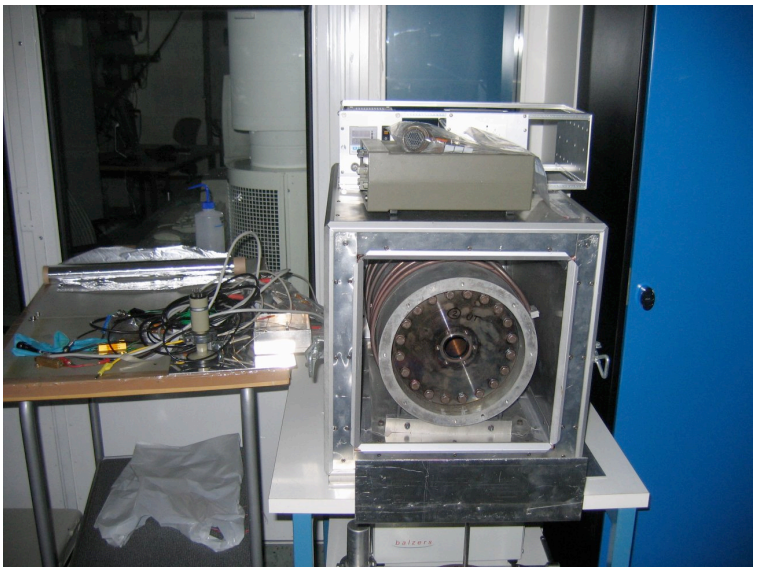


Figure 12: Small vacuum test chamber

4.2.4.1.1 Test Procedure

- Investigate, in a pre-test, the hottest point outside on the pump during operation
- Mount a temperature sensor on the pump
- Mount the pump in the vacuum chamber
- Route power supply cables and temperature sensor cables out of the chamber
- Functional test
- Evacuate chamber, monitoring the temperature of the pump
- Try different operating voltages, find the voltage that gives a stable temperature
- Observe the inside temperature of the box containing the electronics. Especially monitor the temperature of the MOSFETs.

4.2.4.1.2 Acceptance Criteria The pump works under stratospheric pressure conditions. It can be operated at a voltage that gives sufficient throughput of air without overheating the pump. (The throughput of air can be extrapolated, it does not have to be measured.) Sufficient throughput of air is defined as the amount of air

4.2.4.2 Thermal Test A thermal test under ambient pressure conditions will be run for the (operating) pump and for the complete experiment in the cooler / heater shown below. Temperatures of $-60°C$ can be reached.

Figure 13: Small thermal test chamber

4.2.4.2.1 Test Procedure

- Test the pump at $0°C$ with regard to its general behaviour.
- Cool the pump to assess at which temperatures it can safely be restarted.
- Cool the experiment (without the pump) to $-50°C$ or lower and check for any ill effects.

4.2.4.2.2 Acceptance Criteria The pump works satisfactorily at $0°C$ and ambient pressure. It can be restarted at $0°C$, after it has been cooled to lower temperatures. The experiment shows no ill effects at $-50°C$

or lower. The inside of the box containing the electronics should remain in a temperature region where electronic temperature compensation for the pressure sensor is provided, i.e. between $0°C$ and $85°C$.

4.2.4.3 Thermal Vacuum Test A thermal vacuum test can be carried out in the Space Simulator at IRF in Kiruna. The Space Simulator was not chosen as the prime testing facility as it cannot easily be controlled to stratospheric temperatures and pressures. Still, a test run without any criteria is planned provided that the evacuation and cooling process can be stopped around stratospheric conditions.

4.2.5 Structural Testing

The frame will be tested under a series of conditions to makes sure it is adequate for the full operating range.

1. Static load test to be done for a load of 20 kg to represent shock conditions. Will be applied for buckling and bending of the frame structure.

2. Shake test to be conducted using the facilities at IRV. The shaker will be used to conditions as specified by Esrange. This will include all components so that the effectiveness of the electronics and mechanical structure in shake conditions can be seen.

3. Vibration testing will be conducted to investigate the vibrations induced by the pump's motor. The motor will be run until vibrations become fully developed and the amplitude and frequency will be recorded.

The structure is deemed to be adequate so long as it does not fail under the static loading test. The shake test will determine whether the electronic construction and brackets are sufficient during operation.

4.2.6 Full functional test results

An overall functional test (still without batteries) was carried out. It was concluded that the microcontroller works and that the actuators can be moved by controlling them via the ground station. The pump and the heated can be switched on and off and can be regulated via PWM. The temperature sensors give feedback, but the calibration appears to be incorrect. Some flaws in the ground station software were detected.

4.3 Electrical Functional Performance Test

- Functional test of sensors (pressure/temperature) with reference sensors
- Functional and performance test of pump
- Functional test of actuators
- Test of interface between control system and the actuator
- Test of interface between control system and the pump
- Test for EMC
- Full electronic system test in expected temperature and pressure ranges

4.4 Limited Life Time Elements

Batteries will have a limited lifetime and also a continuous performance degradation during the flight. This degradation mainly depends on temperature and the design has to be verified during the testing phase.

5 Ground station

5.1 Ground Control & Electrical Ground Support Equipment

The equipment that is used as EGSE (Electrical Ground Support Equipment) for instrument level and system level check-out testing is also used for experiment ground control during flight and will be referred to as "ground station" below.

5.1.1 Concept

The ground station is kept as simple as possible using standard hardware (a computer notebook) and both standard and custom-made software. The interface between between the experiment on the balloon and the ground station is realised through the E-Link connection. If possible and available, a simulation of the Esrange E-Link should be part of the EGSE.

5.1.2 Hardware Description

A standard notebook or a standard PC with ideally two serial ports (for redundancy reasons) and a replacement unit, both running WindowsXP. A USB-serial converter as a backup. No electrical stimulators will be used during check-out.

5.1.3 Network Interface

A RS-232 connection to the E-Link ground unit, operated at 9600 *bps* or higher, hardware flow control, 1 start, 8 data, 1 stop bit. Can otherwise be suggested by Esrange.

5.1.4 Software Description & User Interface

Stratospheric Census can be controlled from the ground either by a simple terminal program or by the Stratospheric Census Groundstation software. This software is written in the JAVA language and visualises the incoming data and status packets. Additionally, this data is saved in a log-file. Commands are easily executed via simple command buttons ("Experiment Commands"), the response (status packet and/or OK) is displayed. The current status of the connection to the experiment is shown ("Up/Downlink"). If a mission critical command is issued, the operator will be asked to confirm the command in a dialogue box.

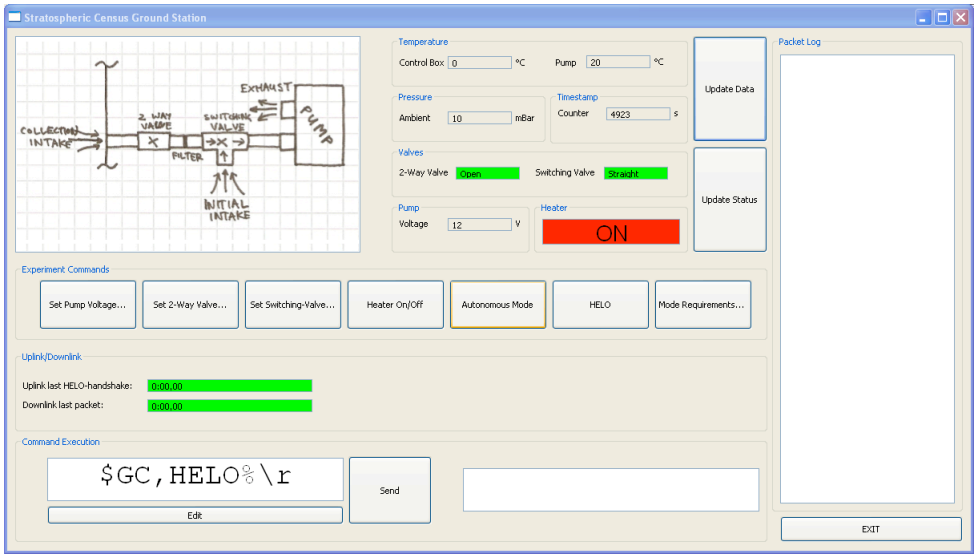


Figure 14: Ground station user interface

5.1.5 Compliance

No further action necessary for the electrical equipment as these are standard components. In general, the working conditions for the ground station are uncritical and the same during development and flight, only satisfactory operation during all other test runs is necessary for compliance.

5.2 Ground Operation Requirements

If the experiment is in "Autonomous Mode", no interaction from the ground is necessary.

If the experiment is in "Normal Mode", the ground operator is mainly responsible for the control of the pump and the valves and the supervision of all data values (temperature and pressure). The following tables gives a summary of all ground operation requirements:

Task	Requirement / Condition	Action
start experiment	floating altitude reached	open check valve set T-valve straight increase pump voltage
stop experiment	floating altitude to be left	set T-valve 90° close check valve decrease pump voltage
lower pump temperature	pump to hot	decrease pump voltage to 1V
raise pump temperature	pump to cold	increase pump voltage to 12 V
change electronics temperature	temperature outside specified range	switch heater on/off as needed
check up- and downlink	-	send HELO-command
modify requirements (pressure/time) for autonomous mode	flight conditions differ from assumptions	send the respective command
manually switch to autonomous mode	uplink failure anticipated	send command

Figure 15: Ground Control Instructions Table

6 Project Management

6.1 Organisation and responsibilities

The team of Stratospheric Census consists of five ambitious students, four from Europe and one from Australia, all studying in the ERASMUS Mundus Master Program "Space Science & Technology" ("Spacemaster"). We have experience in the design of balloon payloads through a CANSAT ("satellite" in a drinking can) competition in the first semester of the study programme. We are:

- Mark Fittock from Australia
  His main responsibility is the mechanical structure of the experiment. He has experience in mechanical engineering.
- Gerrit Holl from the Netherlands
  His main responsibilities are the theoretical and scientific background work and coordinating the documentation.
- Martin Rudolph from Germany
  Martin's field of work is the electronic circuit design and the power budget.
- Martin Siegl from Austria
  Martin has worked on the presentation for ESA, sponsorship allocating, project management, pump information, various small tasks and will do microcontroller programming.
- Jaroslav Urbář from the Czech Republic
  Besides developing the idea of Stratospheric Census, he did research on possible filters.

As a team comprised of five different nationalities, from ESA member countries, an ESA associated country and a non-ESA country, we are proud to reflect the European spirit of ESA in a global cooperation within our group.

6.2 Relation with various organisations

IRV The project has been registered as a course with the Department of Space Physics (IRV), part of Luleå University of Technology (LTU), based in Kiruna, Sweden. The course supervisors are Kjell Lundin and

Alf Wikström. If the supervisors deem the work of sufficient quality, the group members will get 15.0 ECTS credits for the course work.

Progress reports are sent to the IRV supervisors twice a month.

IRV is also one of the funding organisations, providing 5000 Swedish Crowns for parts (primarily electronic components) to be ordered via the institute.

SSC/Esrange The balloon will be launched from Esrange, the launch facility in Kiruna, Sweden operated by the Swedish Space Corporation (SSC) Between April 20 and April 26, a training week was organised at Esrange during which all groups, including the Stratospheric Census group, in both the BEXUS and the REXUS campaigns, presented their PDR's and discussed those with a panel of experts from ESA, DLR, SSC and SNSB.

Eurolaunch Eurolaunch is a cooperation between DLR and SSC. Eurolaunch organises and pays the launch of the BEXUS 7 balloon.

ESA/ESTEC The European Space Agency (ESA) is heading the BEXUS campaign and sponsoring the project by funding the balloon flight. ESA also hosted the selection workshop in March 2008 at ESTEC, Noordwijk, The Netherlands.

IRF The group is close to the Swedish Institute of Space Physics (IRF) and will use some resources available at the IRF for assembling parts of the experiment.

6.3 Schedule and Milestones

Those who fail to plan, plan to fail – Unknown

After Stratospheric Census was chosen for flight, the necessary tasks required to finish the project in time for launch were identified. Rough estimates for the duration of each task were made and a main responsible assigned.

The Gantt-chart in Appendix (F) estimates the overall project duration. This chart was and is continuously updated and the project progresses. Tasks that are already fully completed ("dark") are shown with their actual start and end date. Not yet completed tasks ("light") are shown with their planned start and end date.

Sufficient time was allocated for overall system testing while each component has its own test period as well. Milestones are the PDR, the CDR, the end of the semester and the delivery to Esrange in conjunction with a flight readiness review.

6.3.1 Planning of Phase D

As this CDR report marks the end of phase C ("Detailed Definition"), phase D ("Production/Ground Qualification Testing") can be begun. It includes the assembly steps, in particular assembly on the clean bench that has to be prebooked. The team has decided to assemble parts that might be harmed by contamination as late as possible to avoid any needs of special storage. The main testing campaign is planned mid-September using the IRF space simulator (subject to pre-booking). Note that the different parts themselves are already tested before, individually. This is also to assure that they match the expected quality (e.g. the pump performance) and to be able to return them if need arises.

6.3.2 Important Dates

- April 14th, 2008: PDR deadline (ESA)
- May 8th: PDR deadline (IRV)
- May 26th: CDR deadline (IRV)
- June 2nd: CDR deadline (ESA)
- June 15th: End of the semester at IRV
- July 28th: MTR
- September 8th: EAR
- Flight Readiness Review: September 23
- October 4 - October 10: Launch campaign
- January 15th, 2009: Experiment reported handed in at ESA

6.3.3 Mission Phases

The Stratospheric Census Project is divided into the following phases:

- Production and Testing Phase: The members of the team program and assemble the experiment at IRV in Kiruna, Sweden.
- Mission Phase: The actual flight campaign in October 2008
- Recovery Phase: The filter has to be recovered for analysis. This is handled by Esrange.

- Analysis Phase: The filter is extracted under clean conditions and sent to partner institutes (contacts available) for dust analysis.

6.3.4 Current status

6.3.4.1 Mechanical Engineering The hardware components have been delivered to the team members and assembly has started.

6.3.4.2 Software Engineering The microcontroller has been programmed according to the flow-diagram in the CDR document. Its operation will now be tested and optimised on a model of the PCB, once it arrives.

The ground station software is due to be finished at the end of August.

6.3.4.3 Electronics The PCB board design has been finished, after initial tests had led to changes. It is scheduled to be tested with the microcontroller.

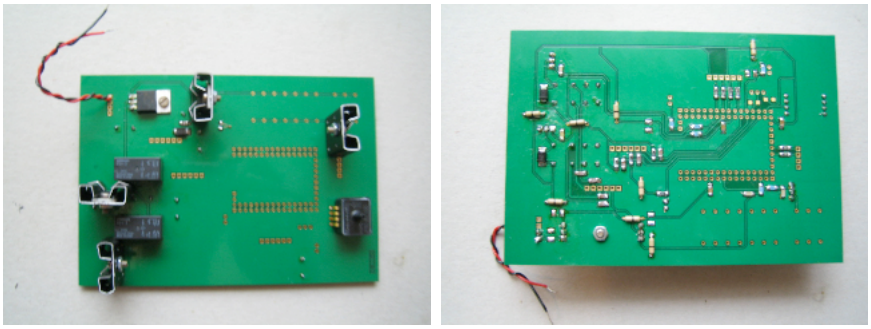


Figure 16: PCB during soldering

6.3.4.4 Pump & Filter The pump has been delivered and will be tested in Kiruna in September (see section about Testing).

6.4 Configuration Control

All changes in the hardware or the software are discussed within the team and reported in the bi-monthly progress reports.

6.5 Deliverables

As mentioned in section (6.2), the group will provide a progress report to the course supervisors around twice a month. A PDR has been delivered to IRV

at May 8th, 2008, as noted in section (6.3.2). The SED is a continuously growing document, which initial version was a project proposal and which grew to a PDR and a CDR. A Flight Readiness Review (FRR) will be carried out September 23 at IRV.

The group will bring two computers and corresponding cables to run the ground station.

A Electronics

A.1 Circuit diagram

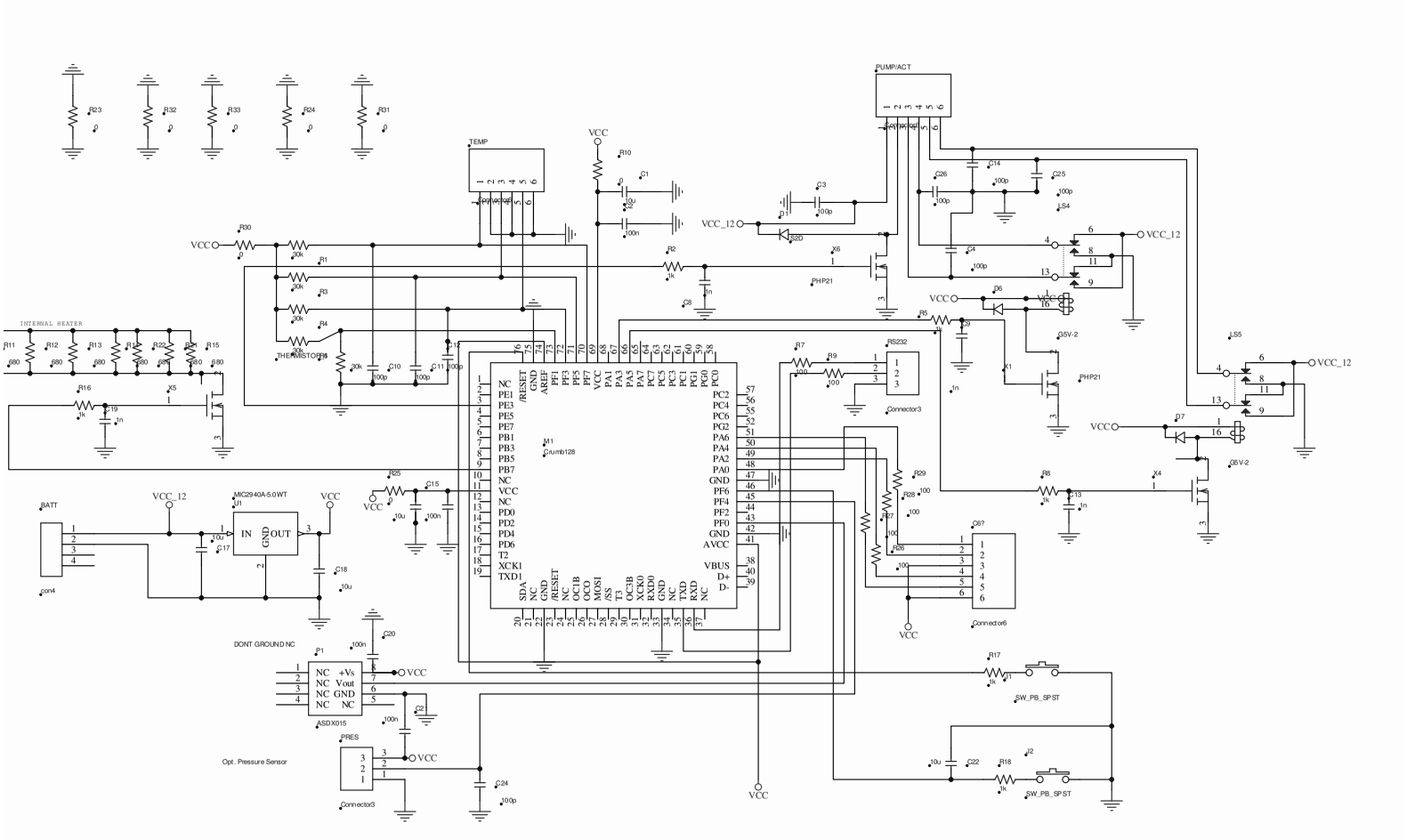


Figure 17: Electronic circuit diagram

A.2 Grounding diagram

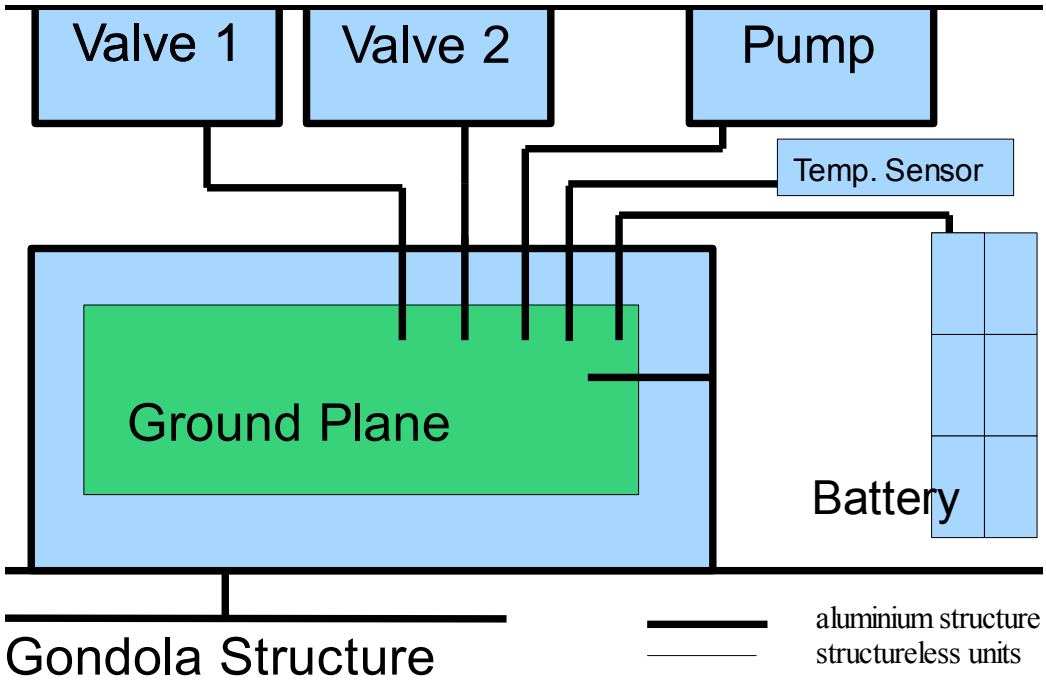
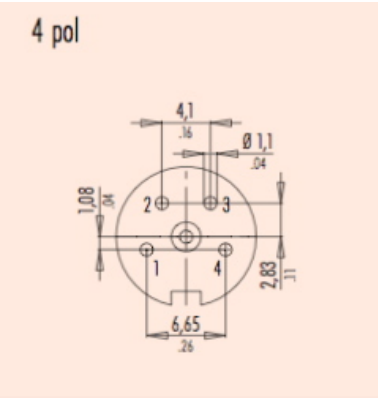
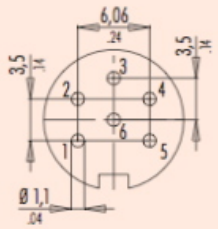
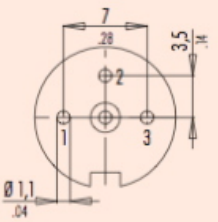
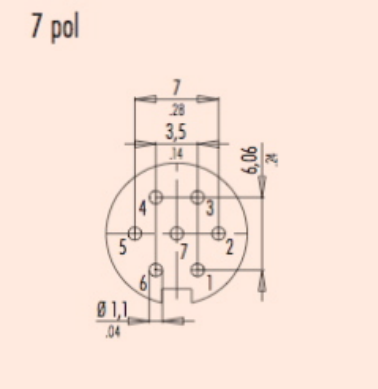
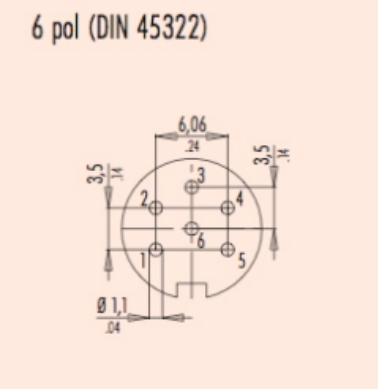


Figure 18: Grounding diagram

A.3 Pin allocation

Interface	# pins	Configuration	Pin Allocation
POW	4		1. V_{cc} (12 V), red 2. GND, blue 3. not used 4. not used

ACT*	6	6 pol (DIN 45322)  	1. Valve 1 (two way), yellow 2. Valve 1 (two way), purple 3. Valve 2 (three way), green 4. Valve 2 (three way), white 5. GND, blue 6. V_{cc} Pump (12 V), red
RS232	3	3 pol (DIN 41524)  	1. RX 2. TX 3. GND

TEMP	7 (one unused)		1. Temp Sensor 1, green 2. GND, blue 3. Temp Sensor 2, white 4. GND, blue 5. Temp Sensor 3, purple 6. GND, blue 7. unused
ACT feedback	6		1. Switch 1, Valve 1, blue 2. Switch 2, Valve 1, purple 3. Switch 1, Valve 2, white 4. GND, blue 5. 5V, red 6. Switch 2, Valve2, green

* The pin numbering for the connectors correspond to the pin numbering in the schematics apart from the ACT interface which on the schematics is numbered as follows:

Pin 1 Vcc pump (12 V)

Pin 2 GND

Pin 3/4 Valve 2

Pin 5/6 Valve 1

A.4 PCB

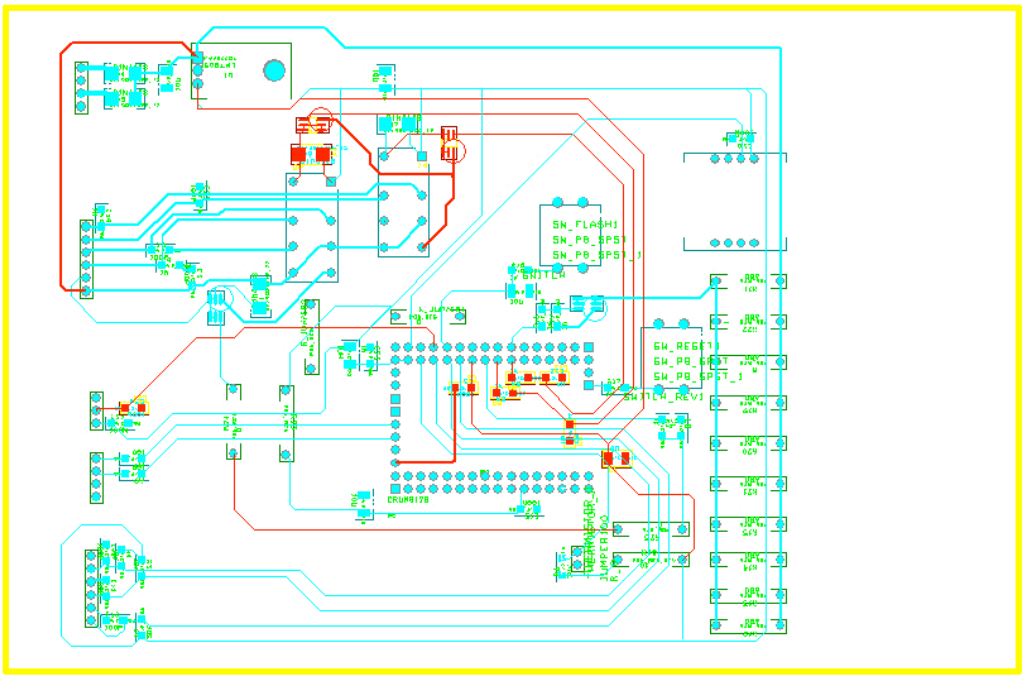


Figure 19: PCB

B Revisions

A table of revisions is shown in table (6).

Date	Version	Changes
Preliminary Design Review		
2008-04-14	1.0	Initial PDR as delivered to ESA
2008-05-05	1.1	Restructuring and various updates
Critical Design Review		
2008-05-19	1.9	Major restructuring
2008-05-26	2.0	CDR as delivered to IRV
Mid-term Report		
2008-07-28	3.0	All brass components were replaced with stainless steel counterparts. Provisions were made to save more status data in the on-board microcontroller EEPROM (on-board backup). Hardware assembly will start earlier than initially planned. Both the electronics and the battery box are designed to be attached with screws on the back side of each box. Initially, plans had been made for using check-valves that close automatically. Due to concerns about opening those valves in the stratosphere, the team decided to use valves that are actuated only electrically. The team is aware that a power failure can lead to these valves not closing. For vacuum test of valves, for thermal tests and for tests of the PCB, the testing section (4.2) was updated.
Experiment Acceptance Review		
2008-09-19	4.0	Updated mass budget, pin allocations, schematics and website, and removed references to abandoned or changed plans
2008-09-22	4.1	More details on pre-flight procedure, wrote on test results

Table 6: Table of revisions

C Outreach Programme

As part of Stratospheric Census we are aware of the importance of reaching out to the public, educating them about the work carried out by the team. We have therefore gotten in contact with Håkan Sjunnesson, writer for (among others) the Swedish popular science magazine "Ny Teknik" (New Technology). In an initial interview, we already explained the project to him and he is going to follow the progress closely.

In September 2008, a website was established, following up on a blog, at:

`http://www.stratospheric-census.org`

A screenshot of the website can be seen in figure (20).

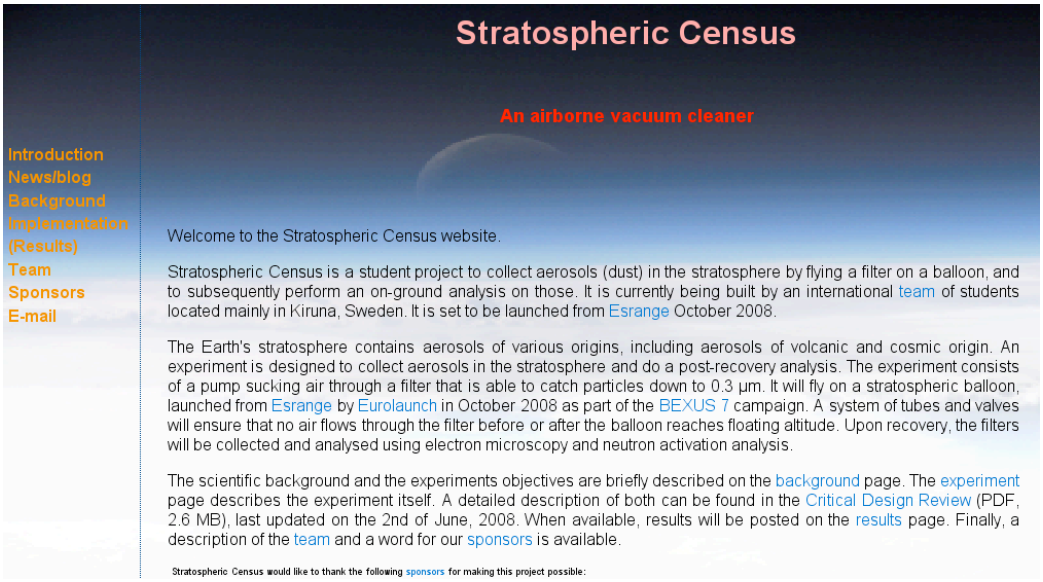

Stratospheric Census
An airborne vacuum cleaner
Introduction
News/blog
Background
Implementation
(Results)
Team
Sponsors
E-mail
Welcome to the Stratospheric Census website.
Stratospheric Census is a student project to collect aerosols (dust) in the stratosphere by flying a filter on a balloon, and to subsequently perform an on-ground analysis on those. It is currently being built by an international team of students located mainly in Kiruna, Sweden. It is set to be launched from Esrange October 2008.
The Earth's stratosphere contains aerosols of various origins, including aerosols of volcanic and cosmic origin. An experiment is designed to collect aerosols in the stratosphere and do a post-recovery analysis. The experiment consists of a pump sucking air through a filter that is able to catch particles down to 0.3 µm. It will fly on a stratospheric balloon, launched from Esrange by Eurolaunch in October 2008 as part of the BEXUS 7 campaign. A system of tubes and valves will ensure that no air flows through the filter before or after the balloon reaches floating altitude. Upon recovery, the filters will be collected and analysed using electron microscopy and neutron activation analysis.
The scientific background and the experiments objectives are briefly described on the background page. The experiment page describes the experiment itself. A detailed description of both can be found in the Critical Design Review (PDF, 2.6 MB), last updated on the 2nd of June, 2008. When available, results will be posted on the results page. Finally, a description of the team and a word for our sponsors is available.
Stratospheric Census would like to thank the following sponsors for making this project possible:

Figure 20: A screenshot of the front page of the website.

Additionally, the team would of course be happy to participate in any outreach effort that ESA plans within its own public relations framework.

D Scientific Analysis

Relevant questions for analysing the scientific relevance of the mission are:

- How long will the flight take?
- What is the geographical extent of the flight?
- What altitude will the balloon reach?
- What is measured?
- What can be determined from the measurements?
- What is the composition of the Earth's atmosphere at the altitude at which the balloon is flying?
- What are the environmental conditions within the balloon gondola?
- What are the constraints imposed upon the experiment by the gondola bus and the other experiments on the gondola?

D.1 Stratosphere

The stratosphere is the atmospheric layer extending from the tropopause to the stratopause. It is roughly the area where temperature increases with altitude. The composition is very similar to that of the troposphere, with nitrogen and oxygen being the dominant elements. The most important difference in the chemical composition is that where the troposphere has a significant amount of water, the stratosphere is very dry, particularly at polar latitudes. The mixing ratio for water has been measured to be between 1 and 3 parts per millions mass at polar latitudes on the northern hemisphere at an altitude between 15 and 20 km [11].

D.2 Stratospheric dust

The first major study into stratospheric dust (also known as stratospheric aerosols) appears to have been published in 1960 by Junge et. al [14]. In this study, an Aitken nuclei counter was used with a pressurised chamber to determine the concentration, size distribution and chemical composition of stratospheric aerosols. A detailed description can be found in the cited paper. The particle concentration at an altitude of 20 to 30km was measured to be less than 1 particle per cubic centimetre for particles smaller and larger than

$0.1\mu m$ in radius, with limited quantitative results on the size distribution, though particles smaller than $0.01\mu m$ were found to have short lifetimes and particles larger than $1.0\mu m$ were found to be rare. Most particles were between $0.1\mu m$ and $1.0\mu m$. Chemical analysis showed a large amount of sulphur, particularly for particles between $0.1\mu m$ and $1.0\mu m$ in diameter. A small amount of silicon and iron was also detected.

Elterman et. al used ground-based optical measurements to determine features on tropospheric and stratospheric dust [6].

A comprehensive study was published in 1975 by Rosen, Hofmann and others, focusing on the global ([24]) and seasonal ([10]) dependence as well as size distribution ([23]) and sources ([9] of dust concentrations using a large number of balloon measurements and a dedicated detector (described in [10]) for particles with a diameter $\geq 0.3\mu m$. Measurements above Barrow, Alaska, United States (71°N) in November 1973 show a mixing ratio of around 6particles/mg air at an altitude of 20km [24]. At "Ice island", at 85°N, a concentration of around 1cm^{-3} was found at the same altitude. Higher altitudes were not measured in this report at those latitudes. Size distributions are given in [23]. The size distribution is almost constant with altitude. A best fit function to the size distribution between 18 and 20 km altitude based partially on measurements by [23] is given in the same paper:

$$N_1(>r) = \frac{N_0}{\sqrt{2\pi}\ln(\sigma_g)} \int_r^\infty \exp\left[-\left(\frac{\ln(\frac{r'}{r_g})}{\sqrt{2}\ln(\sigma_g)}\right)^2\right] \frac{1}{r'} dr' \qquad (3)$$

In equation (3), $N_0 = 10cm^{-3}$, $\sigma_g = 1.86$, $r_g = 0.0725\mu m$. Refer to [23] for a discussion of this equation. One of the lines in figure (21) is a graphical representation of this.

In [9] is reported that the concentration of sulphur above the tropopause is between 0.1 and 0.3 ppbm (parts per billion mass).

There also exist Aitken particles, particles that are smaller than $0.1\mu m$ in diameter. Those are not feasible to detect using the detection method, because available filters do not catch such particles. Therefore, we will not consider such particles.

D.2.1 Dust profiles

Under normal stratospheric circumstances, the bulk of aerosols can be approximated by droplets of 75% H_2SO_4 and 25% H_2O. [18] Volcanic eruptions increase the amount of dust considerably, but the profile is still mainly sulphur, since this is the origin under normal stratospheric circumstances as well.

Key issues in estimating the amount of cometary dust one might expect to find in the stratosphere are the survival upon atmospheric entry and the duration in the stratosphere. Particles that are big enough to survive the atmospheric heating are known as meteorites, fall straight through the stratosphere down to Earth, and are many orders of magnitude larger than what we are studying. The chance of collecting a meteorite is rather small. Particles that are small enough to circularise their orbits and then survive heating and mechanical stress while descending to around 40 km altitude are smaller than $100\mu m$ [3]. As this survival is biased, collection of stratospheric dust does not give representative information to the distribution and composition of interplanetary dust.

The flux of $10\mu m$ particles is around $1\mathrm{m}^{-2}\mathrm{day}^{-1}$, and their density is around $3 \cdot 10^{-4} m^{-3}$. Particles smaller than $2\mu m$ are hard to detect as such, because the total mass is much smaller than the total mass of submicron sulfate aerosols. However, the elements are quite different from those of volcanic origin, and are thus quite possible to detect if any particles have been collected at all, such as iron, nickel, calcium, aluminium, titanium, magnesium. [3]. The composition and form of those depends on the size of the particles, and the exact likelihood to encounter those varies. The identification as extraterrestrial is usually done based on this information, which is not available when analysing with neutron activation analysis.

D.3 Location-specific considerations

D.3.1 Geography and climate

Esrange is located in the municipality of Kiruna, Norrbotten county, in Swedish Lappland, at 67 53' 38" (67.8938) N, 21 6' 25" (21.10694) E at an altitude of approximately 300m. This region has a subarctic climate (*DfC* in the Köppen classification system). In the heart of winter, ground temperature is usually around $-15°$C but temperatures as low as $-48°$C have been recorded. Precipitation is relatively low all-year round.

D.3.2 Balloon Trajectory

Winds at an altitude of 30km are generally westerly between September and April and its velocity is maximal around January-February. The maximum wind velocity that has been observed is $380\frac{\mathrm{km}}{\mathrm{hour}}$ at 10 February 1974. The winds start slowing down early March and turn around by the end of April. During this time, the wind direction is unstable. The flight time during January-February might be as low as $1-2$ hours [4]. In April and September,

flight times of $5 - 10$ hours are likely. Much longer flights are possible, but for political reasons the balloon will descend before flying into Russia. The balloon will land somewhere in northern Sweden. The temperature in the stratosphere at 30km is about $-60°C$ [1].

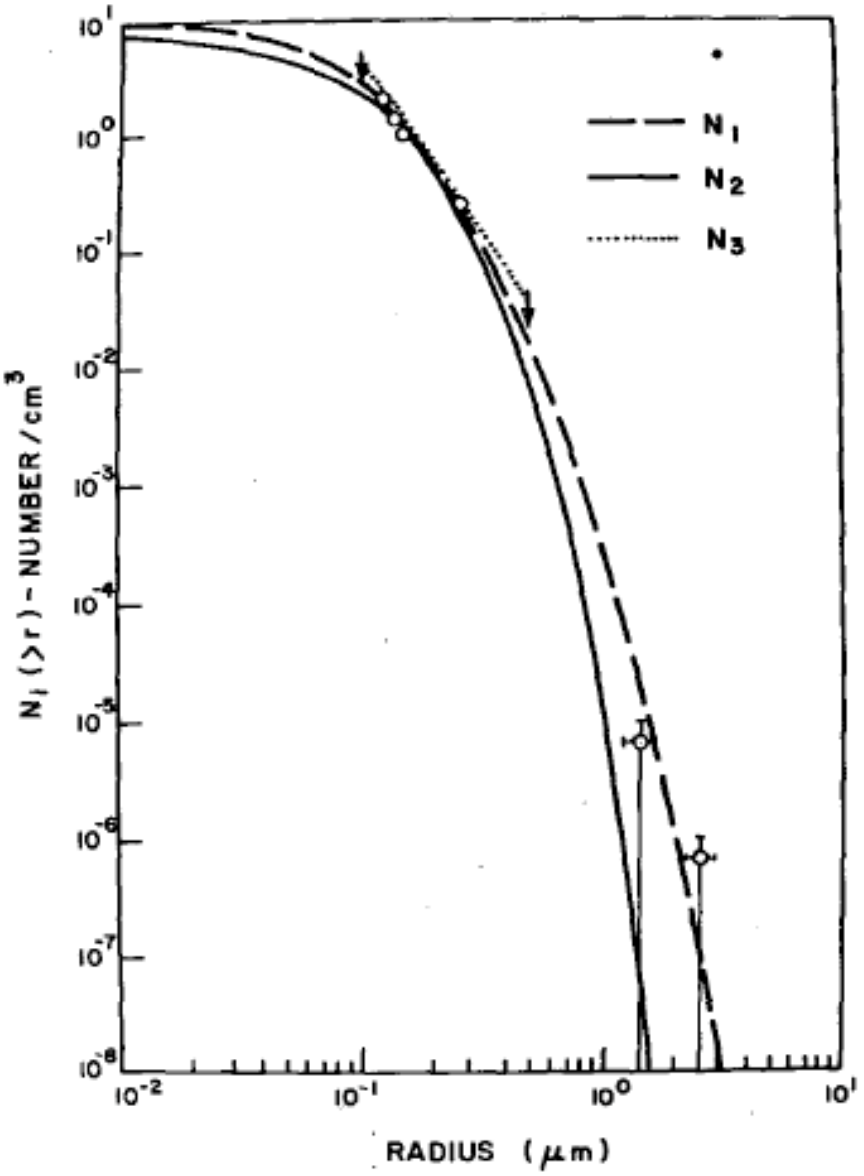


FIG. 3. Integral particle concentration versus particle radius measured by photoelectric particle counter for the 1971–74 period. The data are approximated by log-normal (N_1), exponential (N_2), and restricted power law (N_3) size distribution functions.

Figure 21: Size distribution of stratospheric particles at an altitude of 18 to 20 km. Source: [23]

E Full component list

On the following pages are component lists for the financial budget, the mass budget and the power budget.

Component	Supplier	Ordering Number	Product Number	Qty	Cost / piece	Cost tot (EUR)	Status
Sensors							
Pressure Sensor	Farnell	4197586	ASDX015A24R	1	47.50	47.50	delivered
Thermistor	Farnell	8829560	B57540G303J	4	0.28	1.12	delivered
Connectors							
Circular Con. 680, 3 pins, plug	Binder	N/A	09 0305 00 03	2	4.48	8.96	delivered
Circular Con. 680, 6 pins, plug	Binder	N/A	09 0321 00 06	2	5.06	10.12	delivered
Circular Con. 680, 4 pins, socket	Binder	N/A	09-0312-80-04	1	3.96	3.96	delivered
Circular Con. 680, 7 pins, socket	Binder	N/A	09-0328-80-07	1	5.25	5.25	delivered
Circular Con. 680, 3 pins, socket	Binder	N/A	09-0308-80-03	2	3.78	7.56	delivered
Circular Con. 680, 6 pins, socket	Binder	N/A	09-0324-80-06	2	4.25	8.50	delivered
Connector 7 pin	Farnell	1122588	09 0325 00 07	1	6.45	6.45	delivered
Connector 4 pin	Farnell	1122584	09 0309 00 04	1	5.50	5.50	delivered
Actuators							
Actuator	Airtorque	N/A	Er.10.X53S	2	123.49	246.98	delivered
Pump	KNF Neuberger	N/A	N89KNDC	1	221.46	221.46	delivered
Miscellaneous							
Voltage Regulator	Farnell	1556712	MIC2940A-5.0WT	1	2.90	2.90	delivered
Capacitor 10u	Farnell	1463374	GMK325F106ZH-T	10	0.16	1.60	delivered
Capacitor 100n	Farnell	1520280	C1206S104K5RAC	10	0.10	1.00	delivered
MOSFET	Farnell	1081452	PHP21N06LT	5	0.86	4.30	delivered
Capacitor 100p	Farnell	9753680	B37871K5101J60	10	0.07	0.70	delivered
Capacitor 1n	Farnell	1362558	223858115623	10	0.06	0.60	delivered
Resistor 30k	Farnell	9336320	RMC1/8W 1206 1% 30K	5	0.03	0.15	delivered
Resistor 1k	Farnell	1399764	SR732BTTD1R00F	5	0.13	0.65	delivered
Resistor 100	Farnell	9240888	232272461001	5	0.05	0.25	delivered
Alu Box	Farnell	279110	460-0070	2	27.10	54.20	delivered
Relay	Farnell	9949488	G5V-2 5DC	2	2.54	5.08	delivered
Diode	Farnell	4212873	S2D	3	0.15	0.45	delivered
Capacitor 10u	Farnell	1463374	GMK325F106ZH-T	10	0.16	1.60	delivered
Resistor 1k	Farnell	9337008RL	MC 0.125W 1206 5% 1K	50	0.03	1.55	delivered
Resistor, 0.5W, 300R	Farnell	9340351	N/A	10	0.05	0.50	ordered
PCB	PCBcart	custom design	custom design	1	80.86	80.86	delivered
Batteries	Celltech Stockholm	N/A	Saft LSH 20	8	50.00	400.00	delivered
Resistor 0R	Farnell	9339027	MCF 0.25W 0R	10	0.09	0.90	delivered
Heat Sink	Farnell	265196	PF720	5	0.52	2.60	delivered
Crumb Board w/ Microcontroller	Chip 45	-	-	1	0.00	0.00	delivered
Filter							
Elmarco Nanospider	Elmarco	-	-	2	0.00	0.00	delivered
Mechanics							
Adapter, stainless steel, 1/8” NPT to 1/8” BPT	Swagelok	SS-2-A-2RS	-	1	8.53	8.53	delivered
Anaerobic Thread Sealant	Swagelok	MS-PTS-50	-	1	11.61	11.61	delivered
3-way valve, stainless steel	Swagelok	SS-42GXF2	-	1	83.17	83.17	delivered
2-way valve, stainless steel	Swagelok	SS-42GF2	-	1	73.84	73.84	delivered
Pipe stainless steel, 1/2” OD	Swagelok	SS-T8S-083-6ME	-	1	0.00	0.00	delivered
Flat Nuts (M6) for Solectro Frame	Solectro	209021 0003	-	1	11.30	11.30	delivered
Bolts (M6)	Elfa	48-471-66	-	1	5.27	5.27	delivered
Al Flat Beam	Elfa	48-874-02	-	1m	8.23	8.23	delivered
SUM						1335.20	

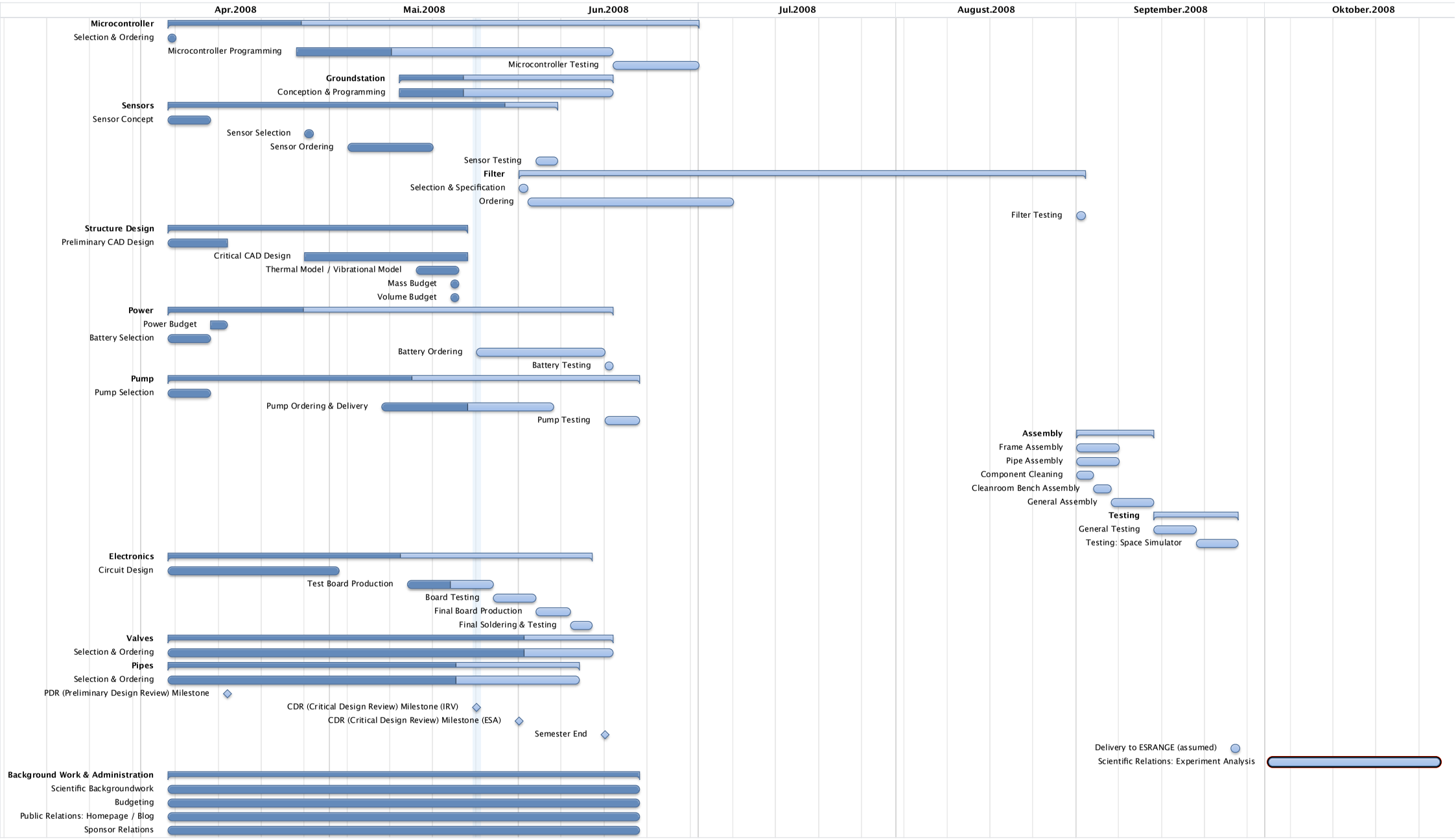
	Power / W
Pump	10.2
Control Unit	5
Heater	5
Actuator	11
total	31.2

Table 8: Power Budget

Items	**Mass (g)**
Frame	1,952.20
Pump	815.30
Control box	730.00
Battery box	609.90
Actuators	1,709.00
Batteries	876.00
Connectors	88.00
Tubing	680.00
Valves	140.00
total	7,600.40

Table 9: The mass budget for the Stratospheric Census Experiment. A conservative estimate for the total mass is 8 kg, allowing for some additions.

F Gantt chart


Apr.2008
Mai.2008
Jun.2008
Jul.2008
August.2008
September.2008
Oktober.2008
Microcontroller
Selection & Ordering
Microcontroller Programming
Microcontroller Testing
Groundstation
Conception & Programming
Sensors
Sensor Concept
Sensor Selection
Sensor Ordering
Sensor Testing
Filter
Selection & Specification
Ordering
Filter Testing
Structure Design
Preliminary CAD Design
Critical CAD Design
Thermal Model / Vibrational Model
Mass Budget
Volume Budget
Power
Power Budget
Battery Selection
Battery Ordering
Battery Testing
Pump
Pump Selection
Pump Ordering & Delivery
Pump Testing
Assembly
Frame Assembly
Pipe Assembly
Component Cleaning
Cleanroom Bench Assembly
General Assembly
Testing
General Testing
Testing: Space Simulator
Electronics
Circuit Design
Test Board Production
Board Testing
Final Board Production
Final Soldering & Testing
Valves
Selection & Ordering
Pipes
Selection & Ordering
PDR (Preliminary Design Review) Milestone
CDR (Critical Design Review) Milestone (IRV)
CDR (Critical Design Review) Milestone (ESA)
Semester End
Delivery to ESRANGE (assumed)
Scientific Relations: Experiment Analysis
Background Work & Administration
Scientific Backgroundwork
Budgeting
Public Relations: Homepage / Blog
Sponsor Relations

G Abbreviations

A list of abbreviations can be seen in table (10).

BEXUS	Balloon EXperiments for University Students
BSPP	British Standard Pipe Parallel
CDR	Critical Design Report or Review
CINAA	Coincidence Instrumental Neutron Activation Analysis
COTS	Commercial Off The Shelve
DLR	German Aerospace Centre
EAR	Experiment Acceptance Review
ESA	European Space Agency
Esrange	European Space Range
IRF	Institut för Rymdfysik (Institute of Space Physics)
IRV	Institut för Rymdvetenskap (Department of Space Physics)
LTU	Luleå Tekniska Universitet (Luleå University of Technology)
MTR	Mid-Term Report
NPT	National Pipe Thread
PCB	Printed Circuit Board
PDR	Preliminary Design Report or Review
PWM	Pulse Width Modulation
SNSB	Swedish National Space Board
SSC	Swedish Space Corporation
TTC	Telemetry, Telecommunications & Command

Table 10: Table of used acronyms

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